TERC

MECHANISMS

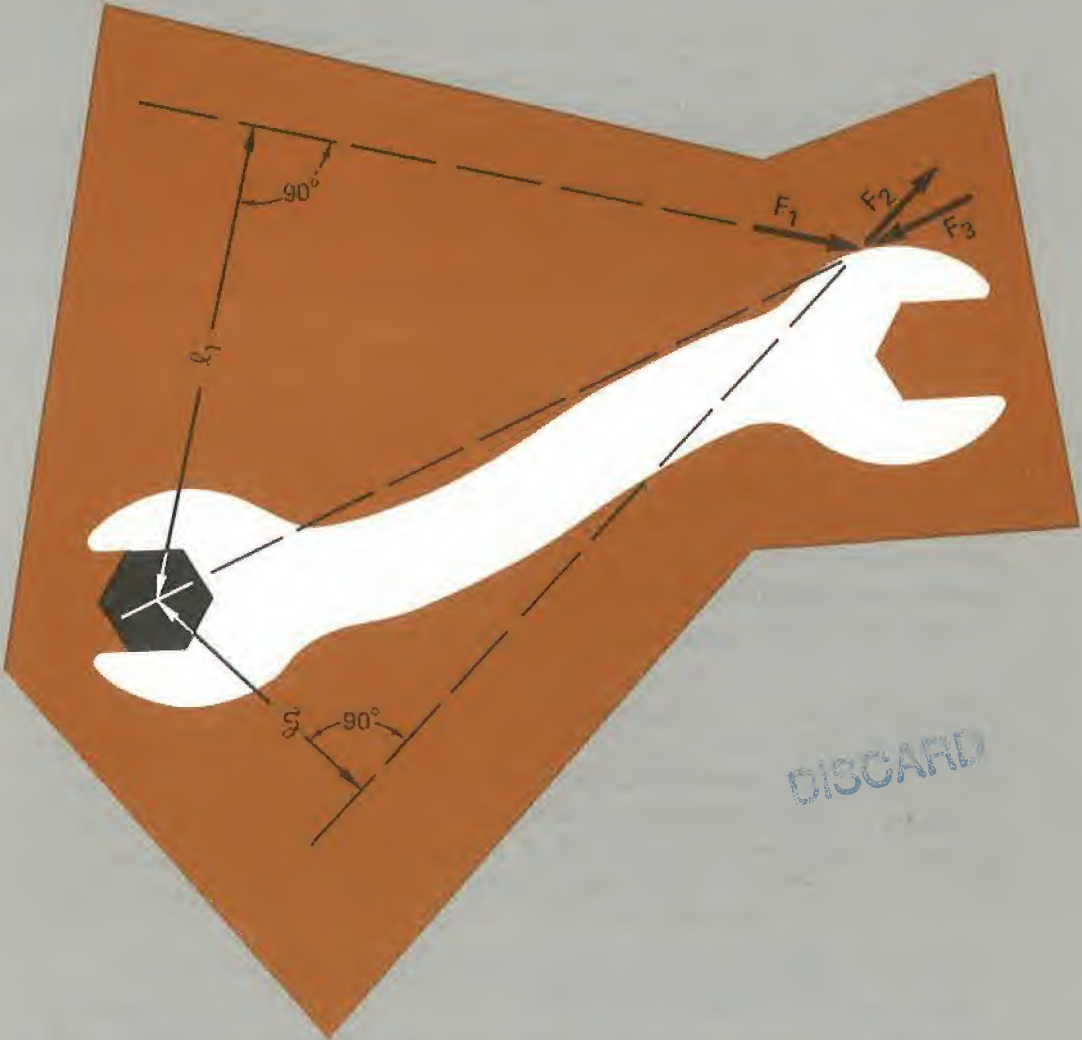
MATERIALS

Electromechanical
Technology Series
TERC EMT STAFF

DELMAR PUBLISHERS, MOUNTAINVIEW AVENUE, ALBANY, NEW YORK 12205

MECHANISMS

MATERIALS



DELMAR PUBLISHERS, MOUNTAINVIEW AVENUE, ALBANY, NEW YORK 12205

DELMAR PUBLISHERS

Division of Litton Educational Publishing, Inc.

Library of Congress Catalog Card Number:
72-75567

PRINTED IN THE UNITED STATES OF AMERICA

Published simultaneously in Canada by
Delmar Publishers, a division of
Van Nostrand Reinhold, Ltd.

The project presented or reported herein was performed pursuant to a grant from the U.S. Office of Education, Department of Health, Education, and Welfare. The opinions expressed herein, however, do not necessarily reflect the position or policy of the U.S. Office of Education, and no official endorsement by the U.S. Office of Education should be inferred.

Foreword

The marriage of electronics and technology is creating new demands for technical personnel in today's industries. New occupations have emerged with combination skill requirements well beyond the capability of many technical specialists. Increasingly, technicians who work with systems and devices of many kinds – mechanical, hydraulic, pneumatic, thermal, and optical – must be competent also in electronics. This need for combination skills is especially significant for the youngster who is preparing for a career in industrial technology.

This manual is one of a series of closely related publications designed for students who want the broadest possible introduction to technical occupations. The most effective use of these manuals is as combination textbook-laboratory guides for a full-time, post-secondary school study program that provides parallel and concurrent courses in electronics, mechanics, physics, mathematics, technical writing, and electromechanical applications.

A unique feature of the manuals in this series is the close correlation of technical laboratory study with mathematics and physics concepts. Each topic is studied by use of practical examples using modern industrial applications. The reinforcement obtained from multiple applications of the concepts has been shown to be extremely effective, especially for students with widely diverse educational backgrounds. Experience has shown that typical junior college or technical school students can make satisfactory progress in a well-coordinated program using these manuals as the primary instructional material.

School administrators will be interested in the potential of these manuals to support a common first-year core of studies for two-year programs in such fields as: instrumentation, automation, mechanical design, or quality assurance. This form of *technical core* program has the advantage of reducing instructional costs without the corresponding decrease in holding power so frequently found in general core programs.

This manual, along with the others in the series, is the result of six years of research and development by the *Technical Education Research Centers, Inc.,* (TERC), a national nonprofit, public service corporation with headquarters in Cambridge, Massachusetts. It has undergone a number of revisions as a direct result of experience gained with students in technical schools and community colleges throughout the country.

Maurice W. Roney

The Electromechanical Series

TERC is engaged in an on-going educational program in *Electromechanical Technology.* The following titles have been developed for this program:

INTRODUCTORY

ELECTROMECHANISMS/MOTOR CONTROLS

ELECTROMECHANISMS/DEVICES

ELECTRONICS/AMPLIFIERS

ELECTRONICS/ELECTRICITY

MECHANISMS/DRIVES

MECHANISMS/LINKAGES

UNIFIED PHYSICS/FLUIDS

UNIFIED PHYSICS/OPTICS

ADVANCED

ELECTROMECHANISMS/AUTOMATIC CONTROLS

ELECTROMECHANISMS/SERVOMECHANISMS

ELECTROMECHANISMS/FABRICATION

ELECTROMECHANISMS/TRANSDUCERS

ELECTRONICS/COMMUNICATIONS

ELECTRONICS/DIGITAL

MECHANISMS/MACHINES

MECHANISMS/MATERIALS

For further information regarding the EMT program or for assistance in its implementation, contact:

Technical Education Research Centers, Inc.
44 Brattle Street
Cambridge, Massachusetts 02138

Preface

The study of materials is essential to all aspects of technology. The technician needs to know about materials and their properties in order to make wise selections of parts and manufacturing processes. The advent of space exploration has demanded a rebirth of interest in materials and their applications. Today, it is necessary to know materials for aerospace, defense weaponry, and precision instrument applications. These changes in emphasis have created subtle, but important, new demands upon training programs in materials.

This instructional material is an introductory treatment of *Modern Materials,* combining the elements of mechanical theory with those of material and its behavior.

The sequence of presentation chosen is by no means inflexible. It is expected that individual instructors may choose to use the materials in other than the given sequence. The type of experiment changes between experiments 7 and 8, and after careful consideration, the instructor may wish to begin with experiment 8, progress through 15, and then proceed with experiments 1 through 7.

The particular topics chosen for inclusion in this volume were selected primarily for convenience and economy of materials. Some instructors may wish to omit some of the exercises or to supplement some of them to better meet their local needs.

The experiments are presented in an action-oriented format combining many of the features normally found in a textbook with those usually associated with a laboratory manual. Each experiment contains:

1. An *INTRODUCTION* which identifies the topic to be examined and often includes a rationale for doing the exercise.
2. A *DISCUSSION* which presents the background, theory, or techniques needed to carry out the exercise.
3. A *MATERIALS* list which identifies all of the items needed in the laboratory experiment. (Items usually supplied by the student such as pencil and paper are not included in the lists.)
4. A *PROCEDURE* which presents step-by-step instructions for performing the experiment. In most instances the measurements are

done before calculations so that all of the students can at least finish making the measurements before the laboratory period ends.

5. An *ANALYSIS GUIDE* which offers suggestions as to how the student might approach interpretation of the data in order to draw conclusions from it.

6. *PROBLEMS* are included for the purpose of reviewing and reinforcing the points covered in the exercise. The problems may be of the numerical solution type or simply questions about the exercise.

Students should be encouraged to study the text material, perform the experiment, work the review problems, and submit a technical report on each topic. Following this pattern, the student can acquire an understanding of, and skill with, modern materials that will be very valuable on the job.

These topics on *Materials* comprise one of a series of volumes prepared for technical students by the TERC EMT staff at Oklahoma State University, under the direction of D.S. Phillips and R.W. Tinnell. The principal authors of these materials are Robert F. Brun and John C. Sheihing.

An *Instructor's Data Guide* is available for use with this volume. Gary Cope, Harlan Cook and Larry Teel were responsible for testing the materials and compiling the instructor's data guide for them. Other members of the TERC staff made valuable contributions in the form of criticisms, corrections, and suggestions.

It is sincerely hoped that this volume as well as the other volumes in the series, the instructor's data books, and the other supplementary materials will make the study of technology interesting and rewarding for both students and teachers.

THE TERC EMT STAFF

TO THE STUDENT

Duplicate data sheets for each experiment are provided in the back of the book. These are perforated to be removed and completed while performing each experiment. They may then be submitted with the experiment analysis for your instructor's examination.

Contents

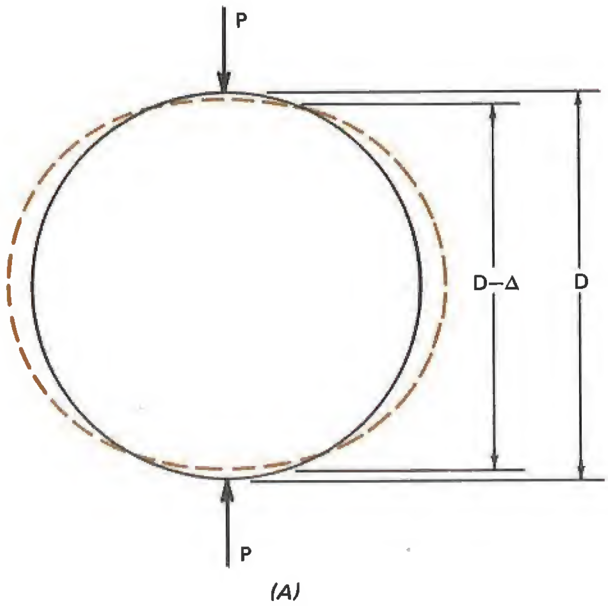
experiment 1 *FORCE MEASUREMENT AND TRANSMISSION*

INTRODUCTION. Materials used in structures and machines must be adequate to carry the forces imposed by the applied loads. We will study principles of force transmission and measurement in this experiment.

DISCUSSION. Force is an action which changes the shape and size of the bodies on which it acts. **Since all bodies react in some way to the presence of a force, we can utilize these reactions to detect not only the presence of a force, but also its magnitude and direction.** As an example, when you step into an automobile, it sinks lower to the ground due to the gravitational force of your weight. This sinking relates directly to your weight. If a second person were to step into this vehicle, his weight could be determined by comparing the additional sink to that total which occurred when you stepped in.

This simple force-deflection relationship is the principle used in most force measuring instruments. These instruments are called by several names, the most common being force transducers or load cells. They may be pure mechanical devices or mechanical with electrical sensing and output signals, mechanical with optical readout, or mechanical to fluid pressure readout.

One of the simplest (and most accurate) types of force transducer utilizes the precise measurement of the deformation of a circular ring as the indication of force. This ring with its precision micrometer screw is called a Proving Ring. It is used as a force calibration standard for science and industry. Figure 1-1 shows a schematic diagram of the ring transducer and the force-deflection relationship.



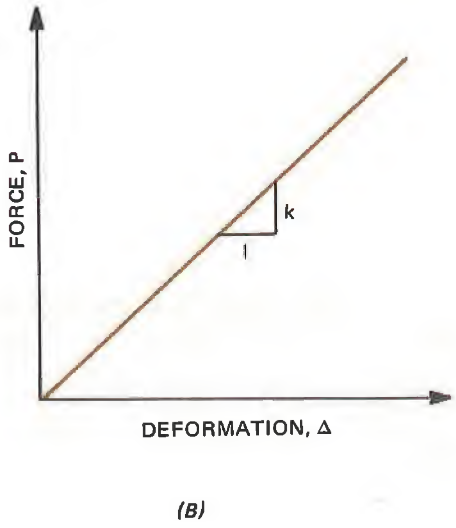


Fig. 1-1 (A) Ring for Force Measurement
(B) Example of Force-Deformation Graph

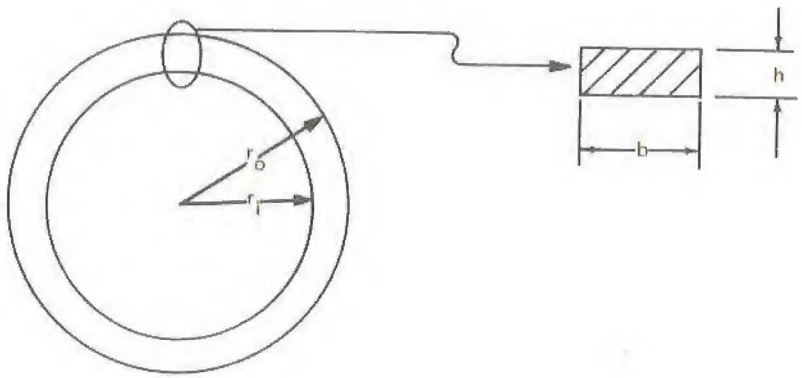


Fig. 1-2 Ring Nomenclature

A good ring will have a straight line force-deflection relationship. The slope of this link, k, is the ring constant. Once this constant is established, force values are easily determined from measured deflections by using the equation

$$P = k\Delta \qquad \textbf{(1.1)}$$

The amount a ring will deform under load is determined by its compliance, C. Compliance is the inverse of the ring constant

$$C = \frac{1}{k} \qquad \textbf{(1.2)}$$

Combining equations 1.1 and 1.2,

$$\Delta = CP \qquad \textbf{(1.3)}$$

and thus, a ring with a large compliance undergoes a larger deformation under a given load than one with a small compliance. Another term often used to describe transducers is sensitivity. **For measuring small forces one needs a sensitive transducer, that is, one with large compliance. To measure large forces a less compliant (less sensitive) transducer must be used.**

Most ring transducers have a rectangular cross section. Using the nomenclature of figure 1-2, the compliance of a thin ring with rectangular cross section may be calculated from

$$\boxed{C = \frac{1.688\, r^3}{E\, b\, h^3}} \qquad \textbf{(1.4)}$$

where E = 30,000 lb/in^2 for steel and $r = \frac{r_o + r_i}{2}$

For example, suppose you are making a ring and must be able to read to the nearest 10 pounds of force using a micrometer screw that reads deflection to the nearest 0.001 inches. The compliance requirement is

$$C = \frac{\Delta}{P} = \frac{0.001}{10} = 10^{-4} \text{ in./lb}$$

Using this result in equation 1.4

$$10^{-4} = \frac{1.688\, r^3}{E\, b\, h^3}$$

Suppose it is convenient to use stock with a mean radius of four inches and one inch wide. The required thickness can now be found.

$$h^3 = \frac{(1.688)\,(4)^3}{(30 \times 10^6)\,(1)\,(10^{-4})} = 0.036$$

$$h = \sqrt[3]{0.036} = 0.33 \text{ inches}$$

The ring constant for this ring will be

$$k = \frac{1}{C} = \frac{1}{10^{-4}} = 10{,}000 \text{ lb/in.}$$

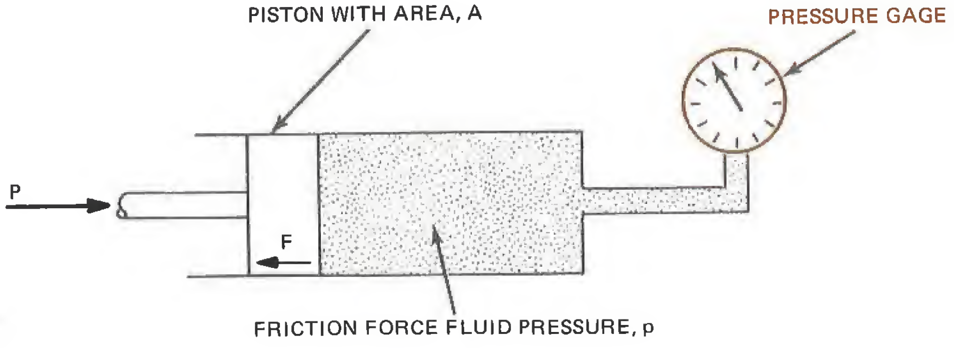


Fig. 1-3 A Hydro-Mechanical Force Transducer

In actual practice it is necessary to calibrate each ring against a known force standard to find the exact value for the ring constant. Differences between specified and actual ring dimensions and approximations inherent in equation 1.4 will result in some difference between actual and calculated values for k (and C).

Another type of force measuring device is pictured in figure 1-3. The force P is transmitted to a piston-cylinder where the force is converted or transduced to fluid pressure. Force, P, and pressure, p, are related through the piston area by

$$\boxed{P = pA} \qquad \textbf{(1.5)}$$

The fluid pressure is read directly from a pressure gage, usually a Bourdon tube gage. One difficulty with this device is that friction force between the piston and cylinder wall reduces the effective force transmitted to the fluid. Taking the friction into account, equation 1.5 becomes

$$\boxed{P - F = pA} \qquad \textbf{(1.6)}$$

where F is the friction force between piston and cylinder and the percent error due to friction is

$$\boxed{\text{error} = \frac{100}{1 + \frac{pA}{F}}} \qquad \textbf{(1.7)}$$

The product pA is the apparent force being measured and F is the unwanted friction force.

Suppose you were using a hydromechanical force transducer which had a piston area of 1.5 in.^{2}. In a separate test, the friction between piston and cylinder was determined to be three pounds. Calculate the error when the pressure gage reads

a) 100 psi
b) 1000 psi

a) The apparent force is pA = 100(1.5)
= 150 lb

$$\text{error} = \frac{100}{1 + \frac{150}{3}} = \frac{100}{1 + 50} = 1.96\%$$

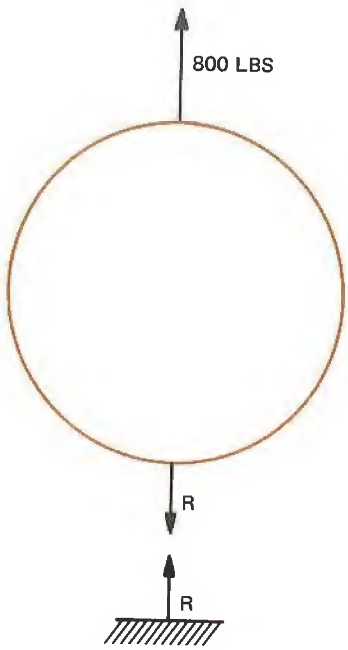
b) The apparent force is pA = 1500 lb

$$\text{error} = \frac{100}{1 + \frac{1500}{3}} = \frac{100}{501} = 0.2\%$$

The percent error of this device is small for high force values. It should not be used to measure low force values unless the friction force (F) is known accurately. In this case equation 1.6 can be used to find the true value of force.

Newton's Third Law applied to forces states that for every applied force there is an equal but opposite reacting force. This law is simple to apply in the case of static forces.

(A) SCHEMATIC OF RING TRANSDUCER WITH 800-LB LOAD



(B) FREE BODY DIAGRAM OF RING TRANSDUCER WITH 800-LB LOAD

Fig. 1-4 Loaded Ring Transducer

Static forces are defined as those which do not change with time or else change so slowly that the effects of inertia can be disregarded. This law can be stated in a very simple equation

$$\boxed{\Sigma F = 0} \qquad (1.8)$$

Equation 1.8 simply says that if we sum all the static forces on a body, both acting and reacting, the result must be zero. In spite of its disarming simplicity, equation 1.8 is a powerful tool for solving static force problems.

You should recognize that equation 1.8 is a vector equation, not a scalar equation. Since forces are vectors, i.e., they have both magnitude and direction, they must be summed using vector methods. The most convenient method for handling coplanar (two-dimensional) force problems is by use of graphics. Figures 1-4 through 1-6 illustrate some simple static force problems and their solutions by graphical means.

The ring transducer is shown in a state of static equilibrium. This means that it is at rest or in a non accelerating condition under the action of the applied forces. According to equation 1-8, all the forces acting on this ring must sum to zero. Figure 1-4B shows a Free Body Diagram of the ring. In the Free Body Diagram, all the physical links which transmit force to the ring are replaced by force vectors representing the force in the link. In this example only one link connects the ring to the foundation. The force in this link is a reacting force. It is properly shown on the ring as a downward force (the force the foundation is transmitting to the ring), and on the foundation, as an upward force (transmitted to the foundation by the ring). Note that reacting forces are differentiated from

acting forces by a slash mark across the vector.

The magnitude of R must be 800 lb acting downward (opposite to the applied load) to satisfy equation 1.8. A force diagram solution to this problem would look as shown in figure 1-5.

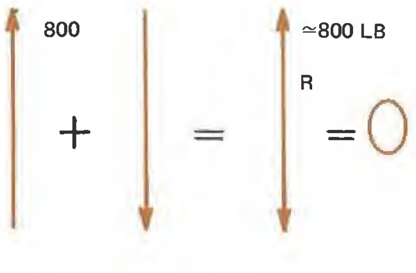


Fig. 1-5 Force Diagram Solution

The graphical construction is begun by laying out to scale the known forces and then constructing the unknown reaction(s) to close the force diagram. Closing is accomplished when the tip of the last vector is brought to the origin or beginning of the first vector. **A CLOSED VECTOR FORCE POLYGON IS A GRAPHICAL SOLUTION OF EQUATION 1.8.**

A second example will illustrate the use of the force polygon. The solution begins by drawing the 1000-lb load to scale and in the proper direction. The magnitudes of R_1 and R_2 are unknown but *the directions of these forces must be along the axis of the links.* Knowing the directions of R_1 and R_2, the force polygon is completed by drawing rays from the base and tip of the 1000-lb load in the directions of R_1 and R_2. The intersection of these rays determines the magnitude of R_1 and R_2.

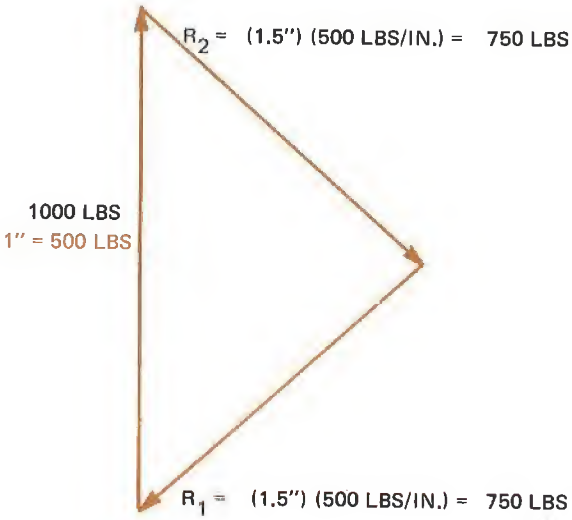


Fig. 1-7 Completion of Force Polygon

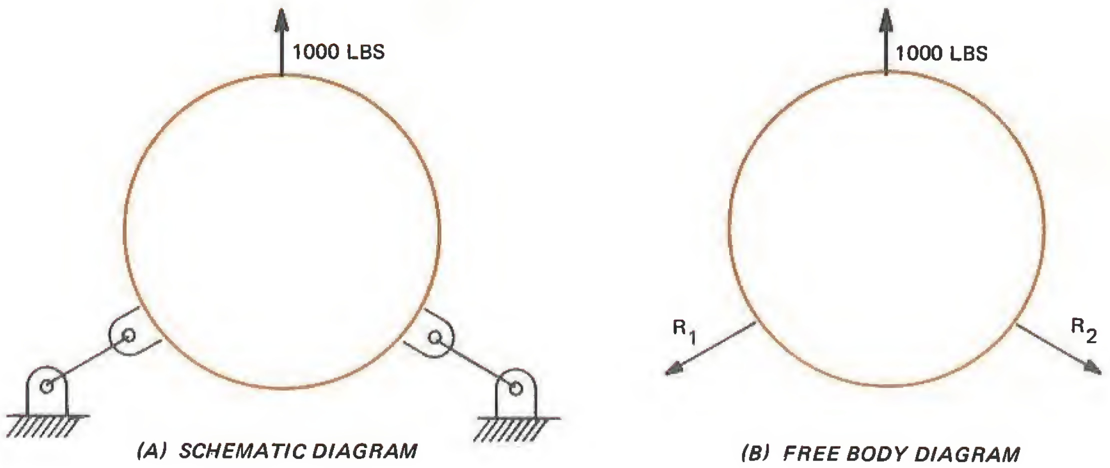
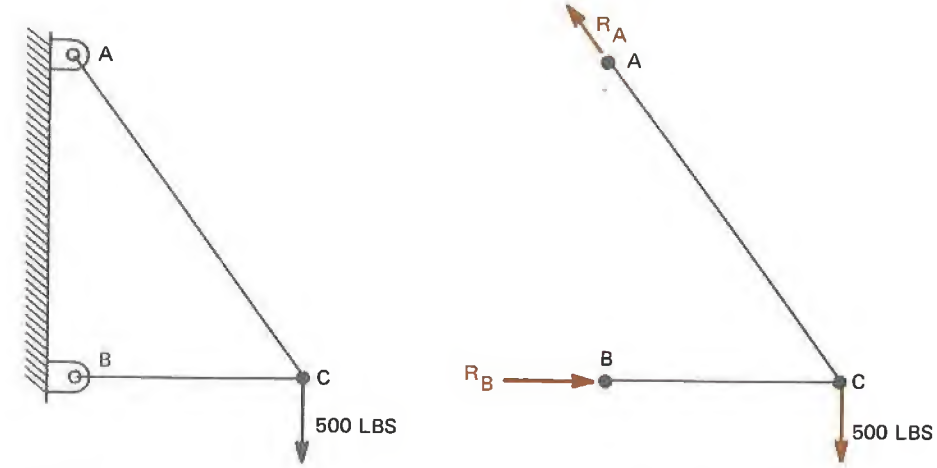


Fig. 1-6 Loaded Ring with Two Supports

A simple frame is shown in figure 1-8. The graphical construction for finding the support reaction forces is shown in figure 1-9. Note by the directions of the reacting forces that link BC is in compression and link AC is in tension.



(A) SCHEMATIC DIAGRAM

(B) FREE BODY DIAGRAM

Fig. 1-8 A Triangular Frame and Load

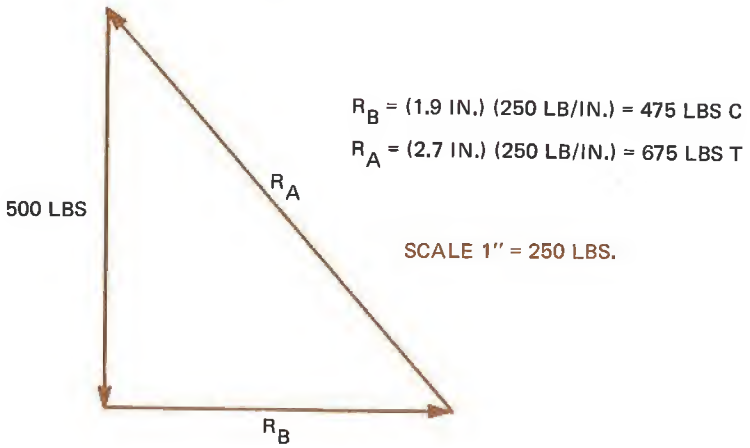


Fig. 1-9 Graphical Solution

MATERIALS

1 Loading frame with 2.5-in. diameter piston
2 Ring force transducers
1 Link, 1-1/2 in.
1 Link, 4 in.
1 Link, 5-1/2 in.
1 Beam member, 4 in.
1 Weight pan
Several 1-lb. and 5-lb. weights

PROCEDURE

1. Inspect apparatus to see that it is in good working order. Pay particular attention to the dial indicators on the ring transducers. They should work freely with no indication of binding or dragging. **Handle them very carefully.**

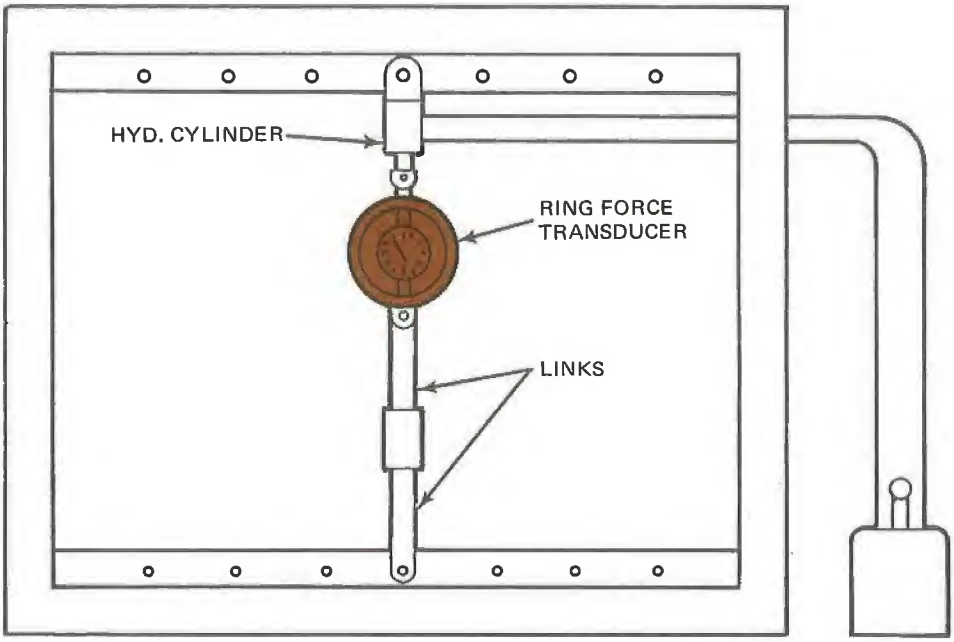


Fig. 1-10 Experimental Setup

2. Connect the hydraulic cylinder to the top rail and hang the weight pan on the piston rod as shown in figure 1-10.

3. Disconnect the hydraulic lines from the pump to the cylinder at the cylinder ports. Connect two open-ended lines to the cylinder.

4. Move the piston to about its mid-position. Hang weights one at a time on the weight pan until the piston begins to move. Record the total weight as friction force F.

5. Connect one ring force transducer to the cylinder and bottom frame using appropriate links. Set the indicator to zero while the links are slack.

6. Load the ring and record hydraulic pressure and ring deflection for every 0.0100 inches up to 0.1500 inches.

7. Repeat steps 5 and 6 for the second ring transducer.

8. Connect both rings in series between the load cylinder and lower frame. Load the cylinder to 1000 psi and read each ring deflection and record.

9. Connect both rings in parallel between the cylinder and frame using the four-inch beam member. Load the cylinder to 1000 psi and read each ring deflection and record.

ANALYSIS GUIDE. The analysis should include determination of the ring constant and compliance for each transducer. You should plot the data on graph paper, check for linearity, and find k and C by calculating the slope from the **best straight line fit** to the data. With the rings in series, was the applied force transmitted equally through each ring? With the rings in parallel was the equilibrium law (equation 1.8) satisfied? What would be a more precise calibration method?

Ring No. 1 F =

Δ	p (psi)	pA	F + pA

Ring No. 2

Δ	p (psi)	pA	F + pA

Fig. 1-11 The Data Tables

Rings in Series

Δ_2	Δ_2	p (psi)	pA	F + pA

Rings in Parallel

Δ_1	Δ_2	p (psi)	pA	F + pA

Fig. 1-11 The Data Tables (Cont'd)

PROBLEMS

1. Measure one of the rings just calibrated and calculate its compliance. Compare it with your experimentally-determined compliance.
2. Two ring transducers each have the same value of compliance, 0.0025 in./lb. Calculate the deflection of each transducer due to a 120-lb load if: (a) they are connected in series; (b) they are connected in parallel.
3. Find the overall compliance for two ring transducers in series in terms of the individual compliances.
4. Find the overall compliance for two ring transducers in parallel in terms of the individual compliances.
5. Same as Problem 3 except ring constant versus compliance.
6. Same as Problem 4 except ring constant versus compliance.
7. Calculate the percent error for these force transducers if the load is: (a) 100 lbs; (b) 1000 lbs.

experiment 2 FORCES IN TRUSSES AND FRAMES

INTRODUCTION. Every member and joint of a machine frame or a truss must be able to carry the load applied to it or the whole structure will fail. In this experiment we will measure the loads in individual members and compare them to calculated values.

DISCUSSION. A frame or truss must be constructed to support the loads imposed on it and to transfer forces due to these loads to foundation anchor points. A rectangular frame is shown in figure 2-1. With force P,

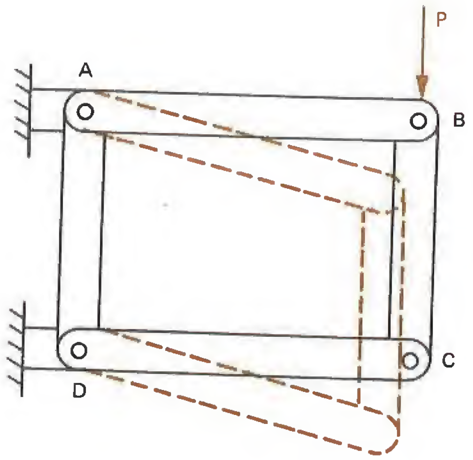


Fig. 2-1 An Unstable Frame

this frame will tend to collapse toward a position shown by the broken color lines. This type of frame is inherently unstable and should not be used to carry large loads. A degree of stability can be built into this frame by fastening gusset plates in the corners or by using some type of rigid joint. The stress on these types of joints is very high however, and such a frame is only useful in lightly-loaded structures. The common household table is one example of the use of this type of unstable frame with rigid corner joints.

The rectangular frame is stabilized by adding a cross member as shown in figure 2-2.

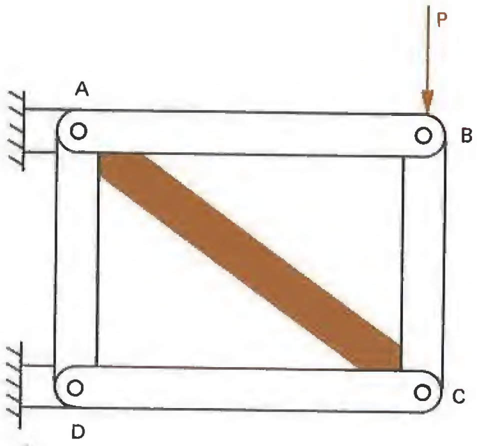


Fig. 2-2 Stabilized Frame

The addition of member AC has stabilized the frame. It will now maintain its shape under load even with pin-connected joints. Using pin connectors is preferred in most instances. **Pin-connected members are not subjected to bending moments that rigid joints can impose. Bending stresses can easily exceed permissible values. Simple tension or compression from pin-connected members is uniformly distributed across the members, resulting in better load carrying ability.**

The pin-connected members are called *two-force* members. They transmit only tension or compression, and the direction of the force is along the axis of the member—along a line connecting the pin holes.

The stabilized frame shown in figure 2-2 is called a **truss**. You can readily see that the

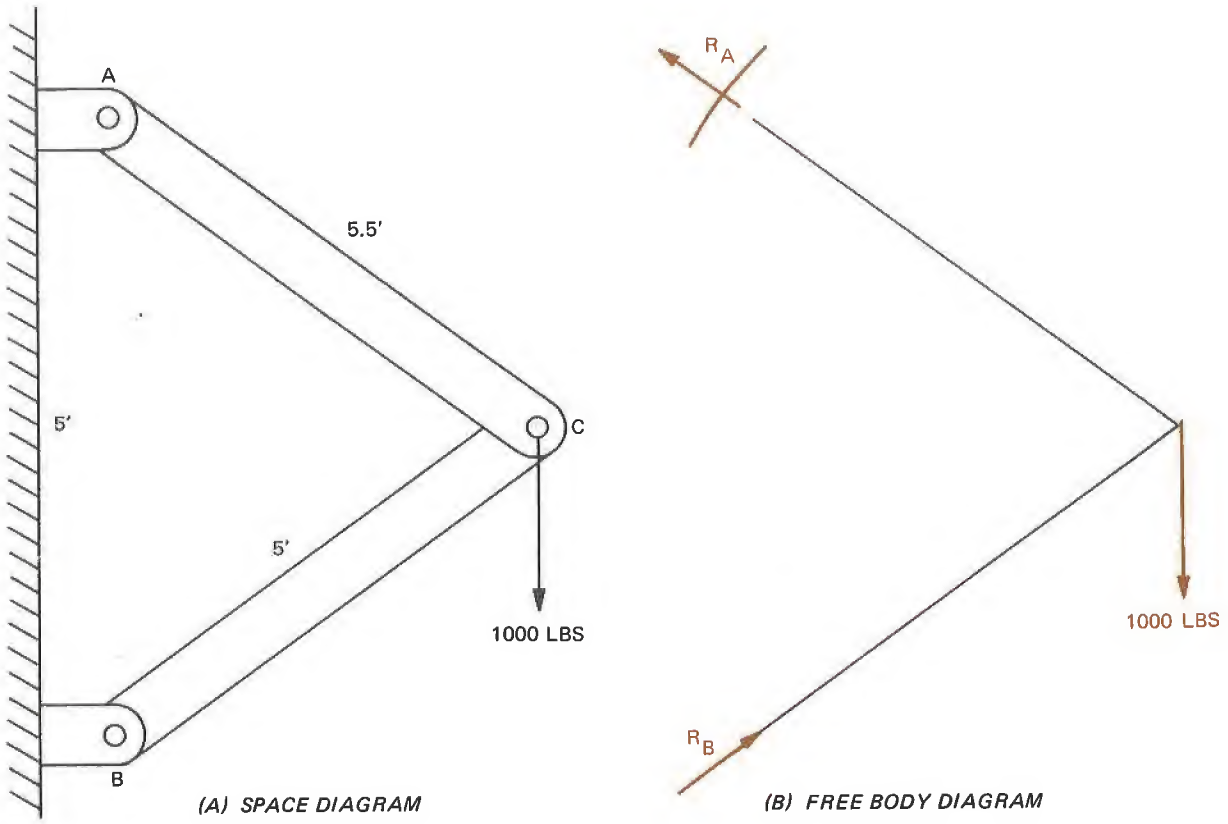


Fig. 2-3 A Simple Pin Truss

basic truss geometry is that of a triangle. **A truss, then, is one or more stable frames connected in such a way as to provide complete structural stability.** Note in figure 2-2 that stabilizing member AC eliminates the need for members AB and BC. These members are now redundant and serve no useful purpose unless they are needed to position the point of application of the load.

The ability of any truss member to carry the load imposed on it depends on the material of the member and its geometry or size. Little progress can be made before the loads carried by each member are known. If a truss is in the design stage, we can use Newton's Third Law,

$$\Sigma F = 0 \qquad (2.1)$$

to find foundation reactions and member forces. For an existing structure, forces may be found by substituting force measuring links for the actual truss members. This is obviously impractical in many instances. In this experiment we will use both methods.

Graphical techniques are illustrated in figure 2-3. **For the simple truss shown, the reactions R_A and R_B are identical to the forces carried in members AC and BC respectively. The direction of these reactions must be along the axis of the members in order to satisfy the law of equal and opposite reacting forces.** We may now proceed to construct a force polygon, figure 2-4. A suitable force scale is selected and the known 1000-lb load

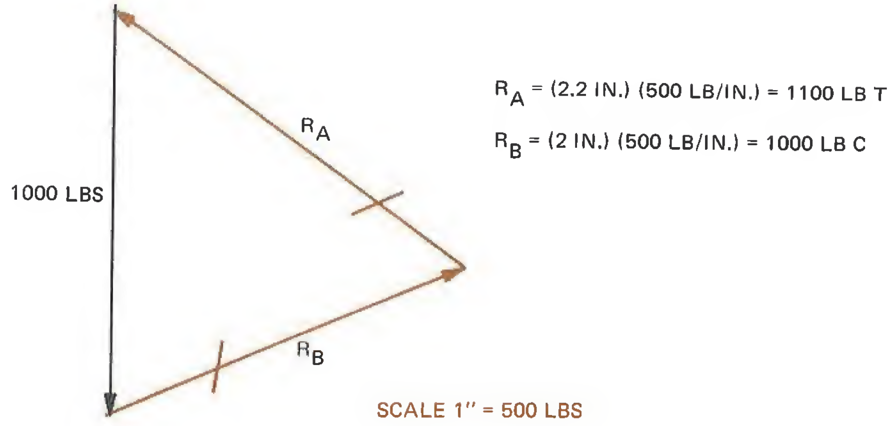


Fig. 2-4 Force Polygon for Figure 2-3

is drawn with proper length and direction. To this force we must add the remaining forces on the truss R_A and R_B. Neither magnitude is known but the directions can be taken directly from the space diagram. Since we use this diagram for finding directions, it is important that it be drawn accurately to scale.

When adding vectors in the force polygon, the arrowheads always follow each other, regardless of the order in which the vectors are added. In the solution shown, the sequence is 1000 lb, R_B, and R_A. R_B is drawn from the tip of the 1000-lb vector in the direction of member BC. Since its magnitude is unknown, it is initially laid out as a long ray. We know the polygon must close when R_A is added, i.e., the tip of R_A must touch the base of the 1000-lb vector. The direction of R_A is known to be along the axis of AC, so a ray is drawn from the base of the 1000-lb vector until it intersects the first ray. This intersection determines the magnitude for both R_A and R_B. The arrowheads are drawn, the vectors scaled, and the corresponding force recorded.

A simple truss supporting a pulley with cable and weight assembly is shown in figure 2-5. Note, in the Free Body Diagram, that the cable tensile force and the force of the weight may be applied at the pin center. This technique can be used for any sheave and cable arrangement. Also note that cable tension is the same on both sides of the idler pulley *if* the bearing friction is negligible.

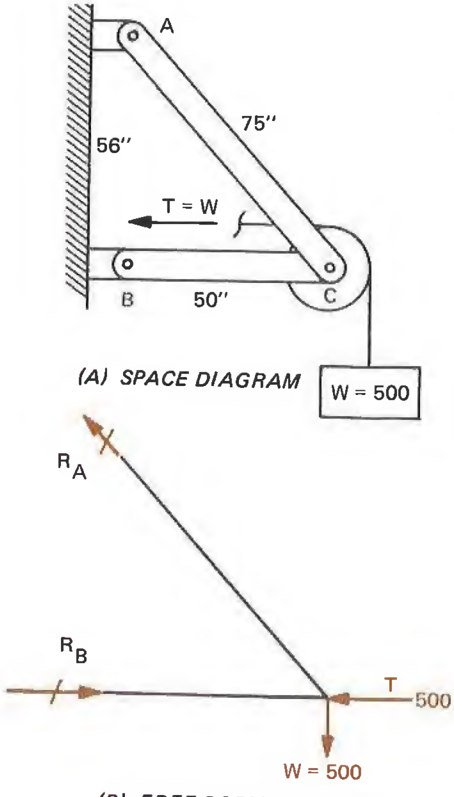


Fig. 2-5 Truss with Pulley and Cable

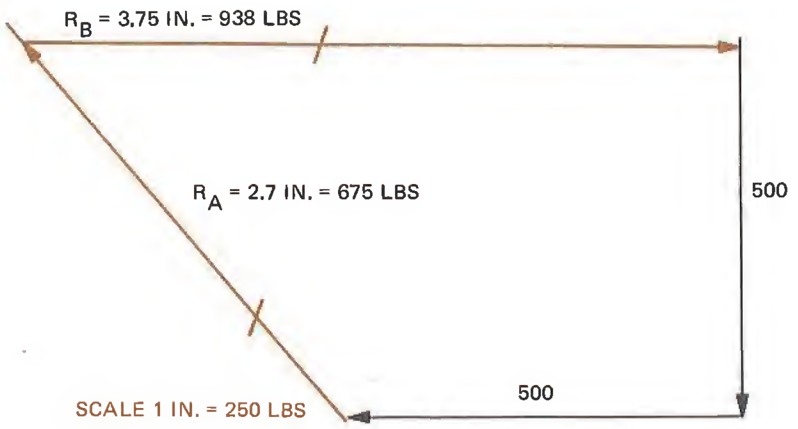


Fig. 2-6 Force Polygon for Figure 2-5

The graphical solution using the force polygon, figure 2-6, clearly shows member BC to have 938 lbs compression and AC, 675 lbs tension.

Most truss solutions require more than finding reacting forces in order to determine member forces. Such a structure is shown in the derrick of figure 2-7. Two members are pinned at joint C so that the reaction force at C is carried by both BC and AC. The reaction force is not equal to the force in either of these members, but rather, equal and opposite to the resultant force in them. To find forces carried by individual members, it is necessary to make free body diagrams at joints A and B. **As you make the imaginary cut in each member to obtain the free body, remember to replace the absent or left behind portion of the member with a force vector representing the action of the missing member on the free body member. The free bodies in figure 2-7 illustrate the technique.**

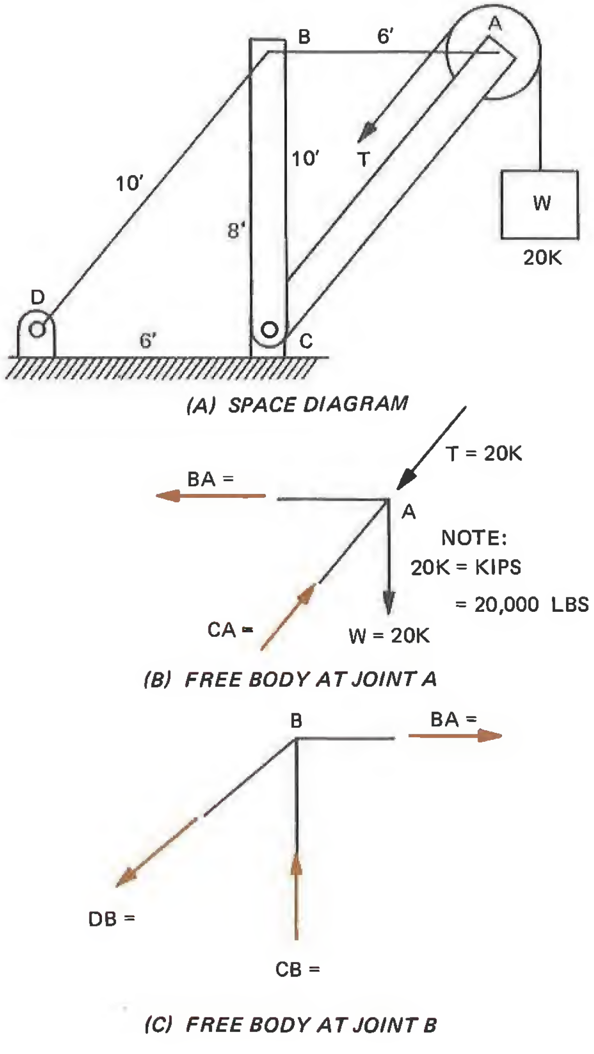


Fig. 2-7 A Derrick Structure

Where you must begin in order to solve this problem is easily determined by inspecting the free body diagrams. None of the forces at joint B are known. At joint A two forces are known and BA and CA can be found by constructing a force polygon. Since force BA

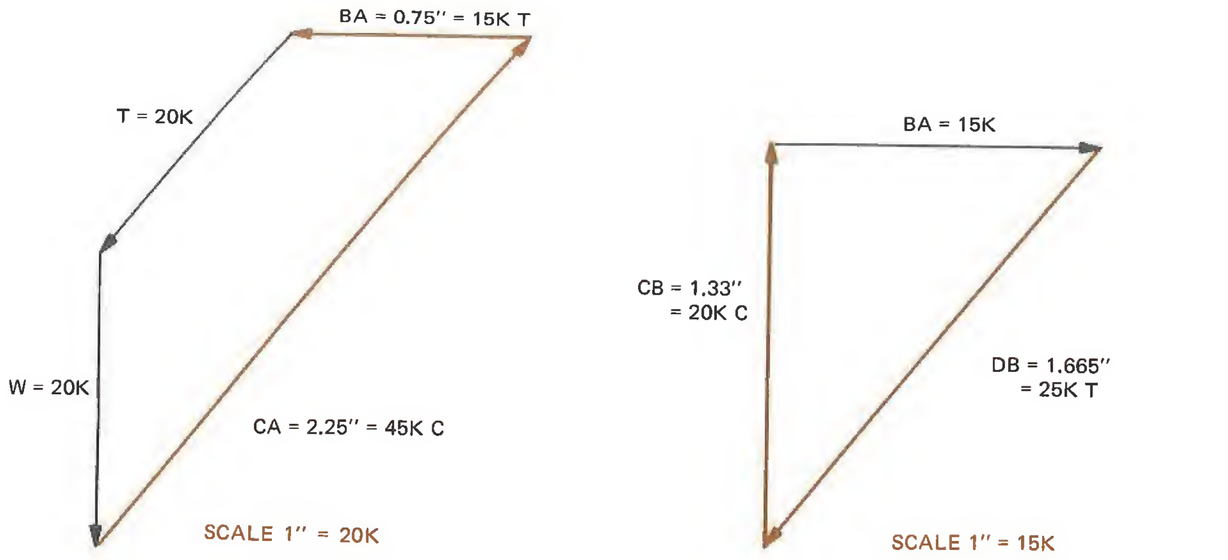


Fig. 2-8 Force Polygons for Figure 2-7

is the same in magnitude at joint A and joint B, one force will now be known at joint B. Next, DB and CB can be found from a second force polygon. After completing the force polygons, the force values should be recorded on the free body diagrams.

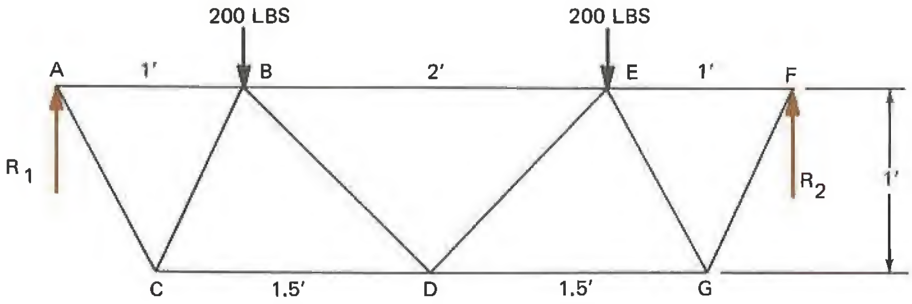
A machine support truss is shown in figure 2-9. Noting the symmetry of the truss and loading, the support reactions can be obtained by inspection. Each reaction must bear half the load. We can take advantage of symmetry in finding truss member loads also. Corresponding members on the left and right will bear the same loads. Consequently, only half the truss needs to be solved.

The sequence to be used for selecting joints on which to draw a force polygon is determined by the number of unknown member forces. The force polygon cannot be solved if there exist more than two unknown member forces. Consequently, you begin at a joint with at least one known force and two or less unknowns and proceed in this way until the forces in all members are known.

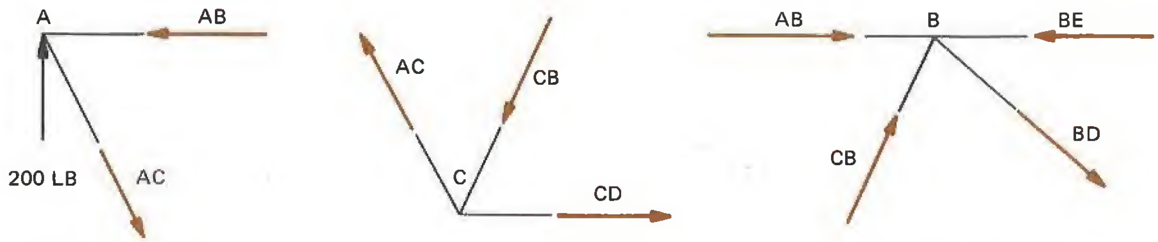
A glance at the joint free body diagrams shows that the first force polygon must be drawn for joint A. At this joint there are two unknown forces AB and AC and one known force. Having solved this joint, AC will be known so joint C can be solved. Knowing AB and CB, joint B can be solved.

When drawing the joint free body diagrams, it is not always obvious which direction the forces should be. If there is any doubt you may leave the arrowhead off until the force polygon is drawn. Solving the force polygon will definitely establish the direction of the forces.

Whether a member is in tension or compression is determined by inspection of the free body diagrams. Force vectors pointing toward the joint indicate a member in compression. Force vectors pointing away from a joint indicate a member in tension. Thus, from figure 2-9B, member AC is in tension (T) and member AB is in compression (C).



(A) FREE BODY OF TRUSS; BY INSPECTION, $R_1 = R_2 = 200$ LBS

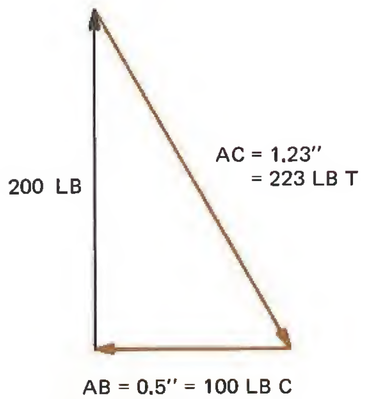


(B) FREE BODY AT JOINT A

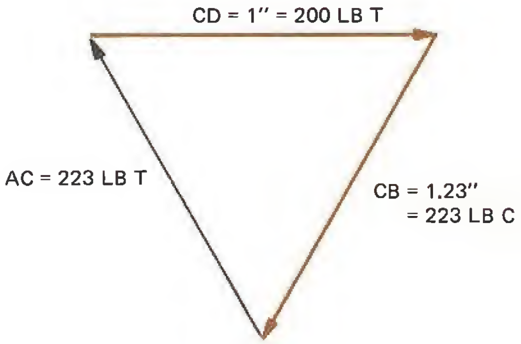
(C) FREE BODY AT JOINT C

(D) FREE BODY AT JOINT B

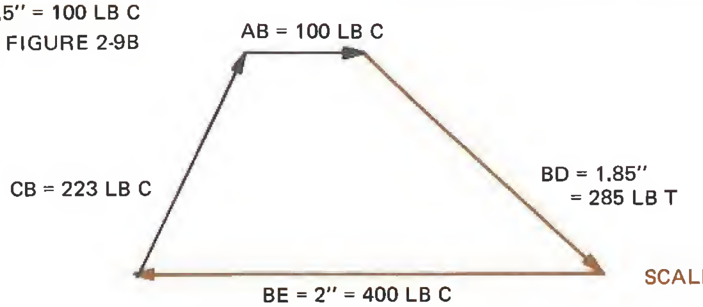
Fig. 2-9 A Machine Support Truss



FORCE POLYGON FOR FIGURE 2-9B



FORCE POLYGON FOR FIGURE 2-9C



SCALE, 1″ = 200 LBS

FORCE POLYGON FOR FIGURE 2-9D

Fig. 2-10 Force Polygon for Figure 2-9

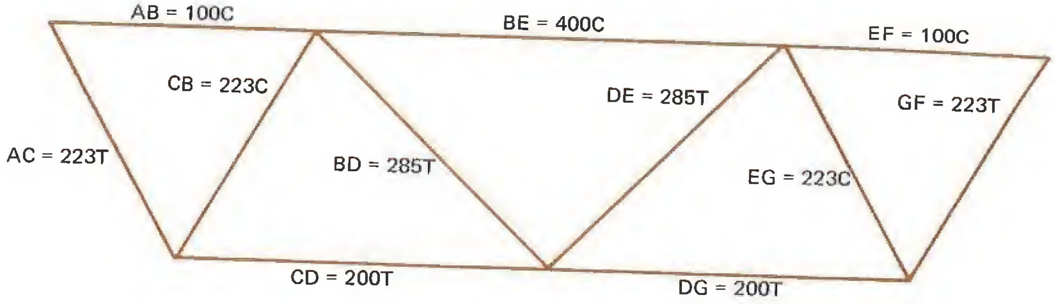
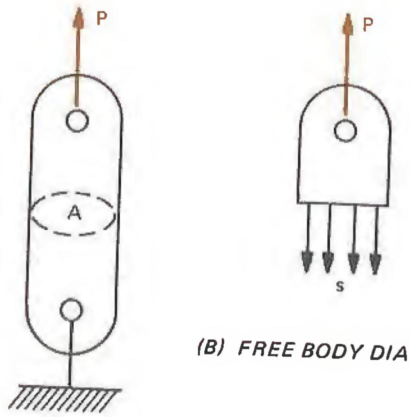


Fig. 2-11 Force-Summation Diagram for Machine Support Truss

The remaining member forces can be found by symmetry. Then EF = AB = 100 lbs C; DE = BD = 285 lbs T; DG = CD = 200 lbs T; etc. All forces found by using the force polygons should be noted on a force summation diagram. This is shown in figure 2-11.

Once the member forces have been found, they can be sized in accordance with the strength of the material used. This is a problem in design. Material strength is specified as an allowable unit stress rating. Each member must be sized so that the actual stress in the member does not exceed the material strength.

Unit stress (usually abbreviated to stress) is defined as the force exerted per unit area of material. Figure 2-12 illustrates this concept.



(A) SPACE DIAGRAM

(B) FREE BODY DIAGRAM

Fig. 2-12 Bar Subject to Tensile Load

A uniform bar of area A is subject to load P. The bar must transmit this force internally from point of application to the foundation or point of attachment. The free body diagram, figure 2-12B, shows schematically the internal forces distributed across the cross section.

We can use equation 2.1 to find the unit stress, s. For equilibrium, the upward force, P, must be balanced by the total downward force. This downward force must be the force per unit area, s, multiplied by the cross section area, A.

$$\boxed{P = sA} \qquad (2.2)$$

or

$$s = \frac{P}{A}$$

Equation 2.2 is in an analysis form. For design, it is rewritten as

$$\boxed{A = \frac{P}{s_a}} \qquad (2.3)$$

The value used for s_a in equation 2.3 is a design or allowable value. Different allowable stress values exist for the many types of materials. Recommended allowable values for structural steel are given by the **American Institute of Steel Construction**, for example. Allowable values depend on the mechanical properties, the application, and, particularly, the consequences of structural failure.

As an example, let's determine the diameter of a round bar that will carry the load of member BE in figure 2-11 if it is made of ASTM-A36 carbon steel. The overall allowable compressive stress for A36 steel is 22,000 psi.

$$A = \frac{P}{s_a} = \frac{400}{22000} = 0.0182 \text{ in.}^2$$

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(0.0182)}{\pi}} = 0.152 \text{ in.}$$

The nearest larger size standard round stock is 3/16" which would be specified.

A problem exists with compression members that are long and slender. They are very prone to failure by column action. Column failure occurs due to instability of the member in compression rather than failure of the material itself. You can demonstrate this to yourself (and your friends) by pushing on an ordinary yardstick. It will initially resist your push but as you increase the load it suddenly buckles. This is column failure. If you didn't push too far, it will spring back again good as before. The material has *not* failed. A 3/16-inch rod two feet long would be likely to fail in this way. You can check for column failure with design equations found in any text on Strength of Materials. This problem does not exist for members in tension.

Suppose the truss of figure 2-9 had already been built. By substituting force transducers for the members, you found the forces in each member as shown in figure 2-11 when the truss was loaded with the two 200-lb loads. You measure member BE and find it to be rectangular bar stock 1" X 1 1/4" and made of ASTM-A36 steel. What will be the permissible loads on the truss if all members had the same cross section?

Since BE carries the largest force of any truss member, it will limit the allowable load. Member BE can carry

$$P = As = (1)(1.25)(22000)$$

$$P = 27{,}500 \text{ lbs}$$

The permissable applied loads are scaled in direct proportion as follows:

$$\frac{27{,}500}{400} = \frac{\text{new load}}{\text{200-lb load}}$$

New Load = 13750 lbs applied at joints B and E. Again, member BE should be checked for buckling.

MATERIALS

- 1 Loading frame with 2 1/2-in. diameter piston
- 2 Ring force transducers
- 11 4 1/2-in. links
- 14 Joint connectors
- 2 Connectors, 1 in.
- 1 Box of 1/4-in. pins

PROCEDURE

1. Inspect apparatus for proper working order. Check dial indicators for proper working order.

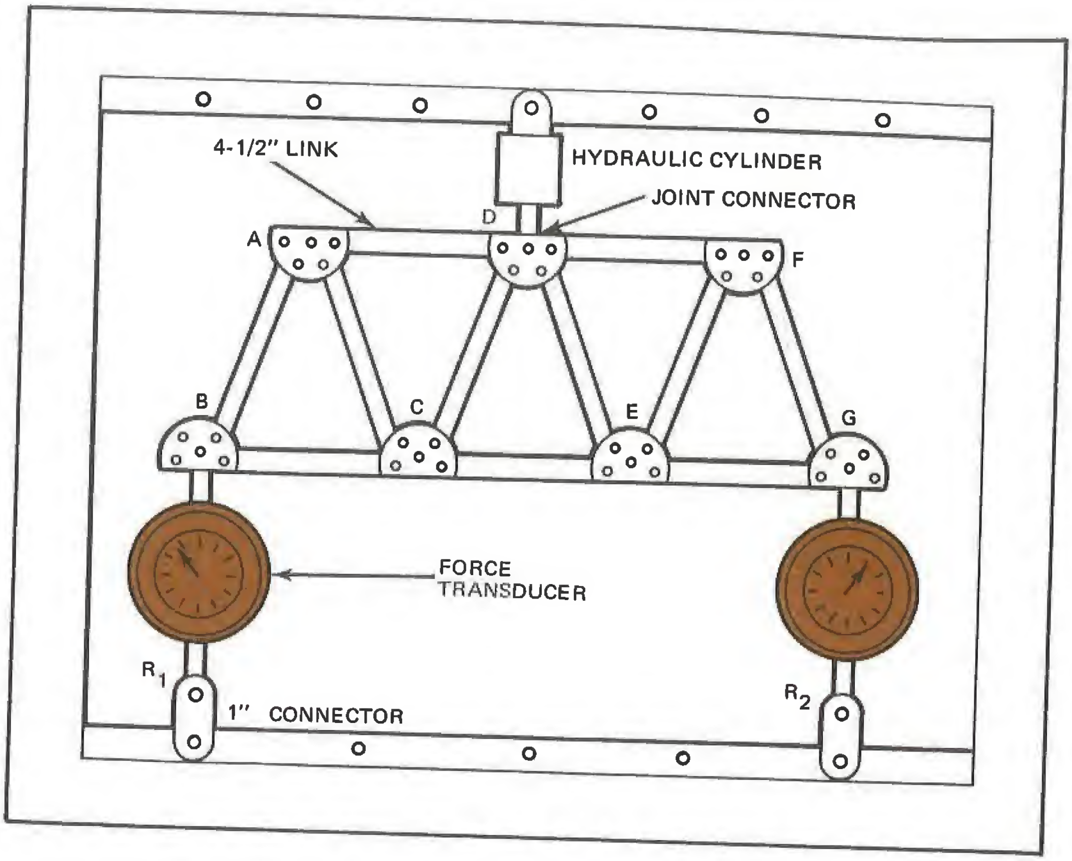


Fig. 2-13 Experimental Setup

2. Assemble the truss shown in figure 2-13. Use the two ring transducers to connect the truss to the lower frame rail.
3. Assume a load P from the cylinder of 500 lbs and use graphical methods to determine the forces in each truss member. By symmetry each reacting force should be 250 lbs.
4. Place a 500-lb upward load on the truss with the hydraulic cylinder. Read and record the reacting forces. Note that for joints which connect links with compressive forces, stabilizing pins should be used to prevent the joint connector from twisting.
5. Replace the force transducers with 4 1/2 in. connecting links and replace two truss members with the force transducers. Load the truss to 500 lbs and record the link forces.
6. Continue replacing links with force transducers and recording forces due to a 500-lb load until all truss member forces have been found.

ANALYSIS GUIDE. Construct a force-summation diagram for this truss. Show the predicted force values from the graphical solution on one side of each truss member and the measured values on the other side. What percent difference is there between these values? Are the errors in the experimental measurements large enough to explain the differences? Does the ring transducer introduce any error in the force measurement?

Force Transducer #1 **k =**

Transducer Position	Deflection Δ	Force, lb P	Hyd. Press p	Piston Area A	Load, lb

Force Transducer #2 **k =**

Transducer Position	Deflection Δ	Force, lb P	Hyd. Press p	Piston Area A	Load, lb

Fig. 2-14 The Data Tables

PROBLEMS

1. Construct a force-summation diagram for this truss and record on it the force that would exist in every link if the applied load were 2750 lbs.

2. Determine the largest allowable load on this truss if the allowable stress in the links used is 20,000 psi.

3. A flexible hoisting rope passes over a pulley at joint C of the truss shown in figure 2-15. Find the force in members AC and CB. Does this structure utilize the triangular frame?

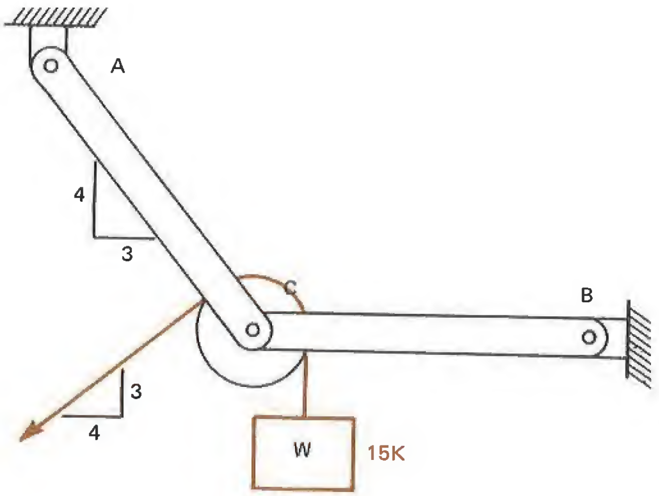


Fig. 2-15 Diagram for Problem Three

4. Find the forces in all the members of the truss shown in figure 2-16. Draw a force-summation diagram.

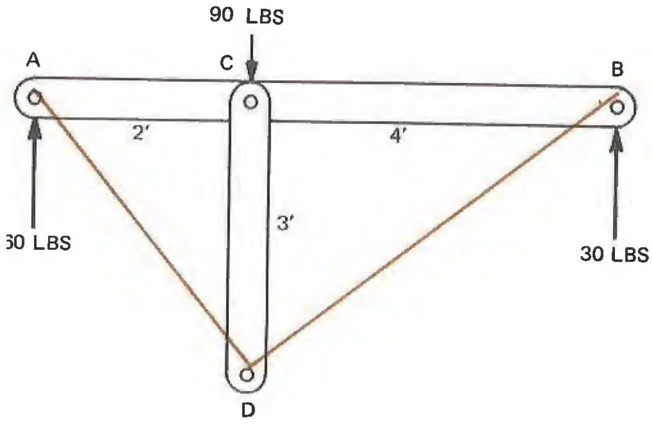


Fig. 2-16 Diagram for Problem Four

experiment 3 MOMENTS OF FORCES–EQUILIBRIUM OF STRUCTURES

INTRODUCTION. All structures in equilibrium must have a balance of moments as well as balance of forces. In this experiment we will study equilibrium using moments of forces.

DISCUSSION. **A line coincident or colinear with a force vector is called the line of action. At any point away from the line of action a force tends to produce rotation of the body on which it acts. This tendency for rotation is the moment of the force. The measure of a moment is the product of the force and the perpendicular distance from the line of action to the point of rotation.** These ideas are illustrated in figure 3-1.

The moment felt by the bolt head has magnitude:

$$M_A = F\ell \;\} \text{ (lb-in.) or (lb-ft)}$$

and the direction of the moment is clockwise. The center of moments is the intersection of the axis of the rotation with the plane formed by the line of action and the moment arm.

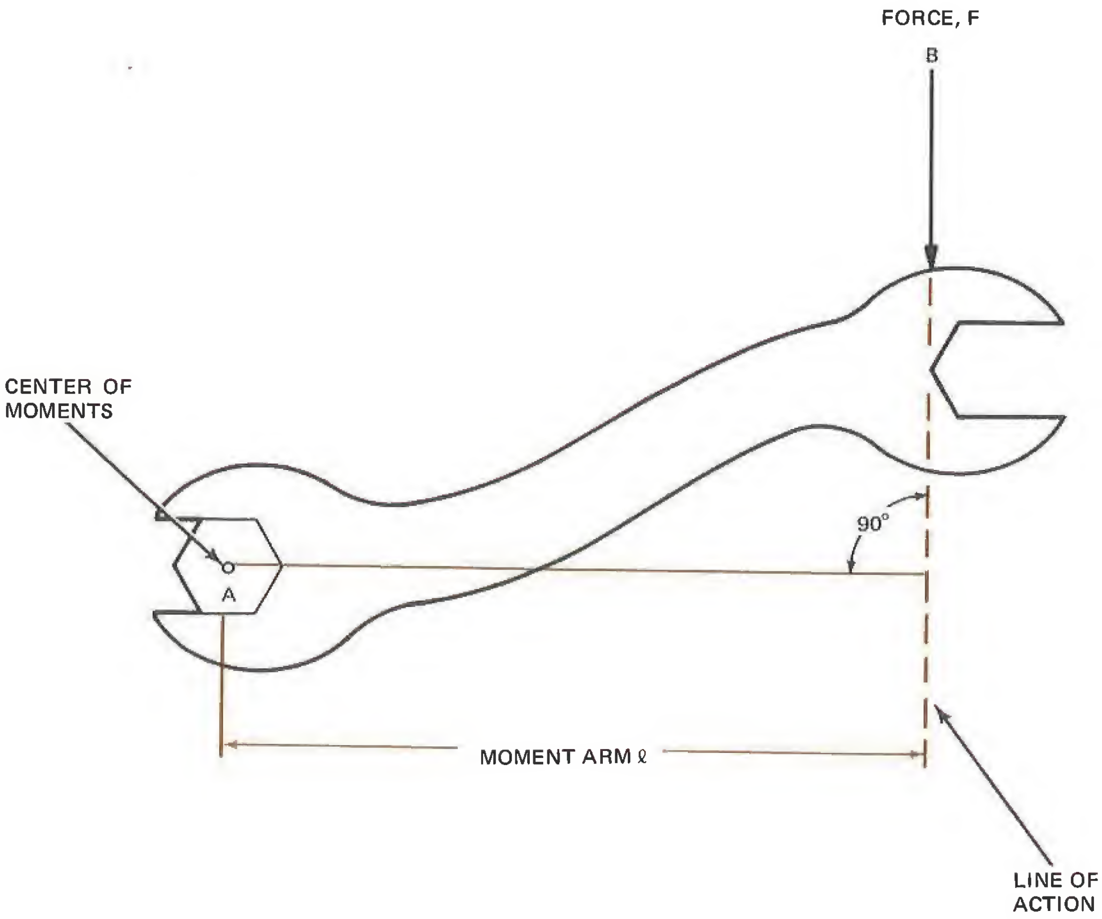


Fig. 3-1 Nomenclature for Moments

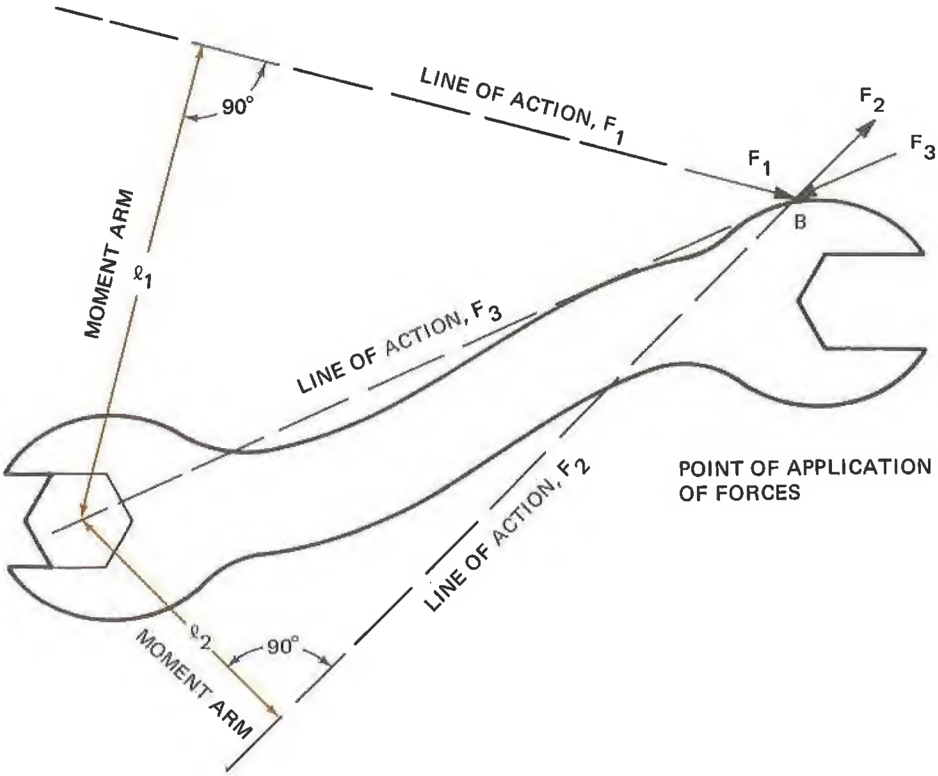


Fig. 3-2 Variations in Moment

The determination of moment arm length must be well understood to make correct calculations of moments. Note in figure 3-2 that for the same point of application as shown in figure 3-1, a force can produce moments about point A that vary from zero to some maximum value in either direction. The moment of force, F_1, is $F_1\ell_1$, for force F_2 it is $F_2\ell_2$, and F_3 produces no moment about point A because the line of action of F_3 goes through point A.

The moment of any force about a point on the line of action of that force must be zero. The direction of a moment is determined by noting whether the force produces a clockwise (↷or CW) turning tendency or a counterclockwise (↶or CCW) turning tendency.

For any given force the maximum moment is produced when the moment arm is a maximum length. A glance at figure 3-2 will disclose that a moment arm can have a length from zero up to the distance between the moment center and the point of application of the force. **This distance between moment center and point of force application is the maximum moment arm.** The direction of the line of action must be perpendicular to the maximum moment arm to obtain maximum moment.

The principle of moments or Varignon's Theorem allows us to calculate the moment of a force by summing the moments due to the components of the force. In many instances this greatly simplifies the calculation. This is illustrated in figure 3-3.

The moment of force P about point A is $P\ell$. We can find ℓ by noting ΔAEB is similar to ΔDFB.

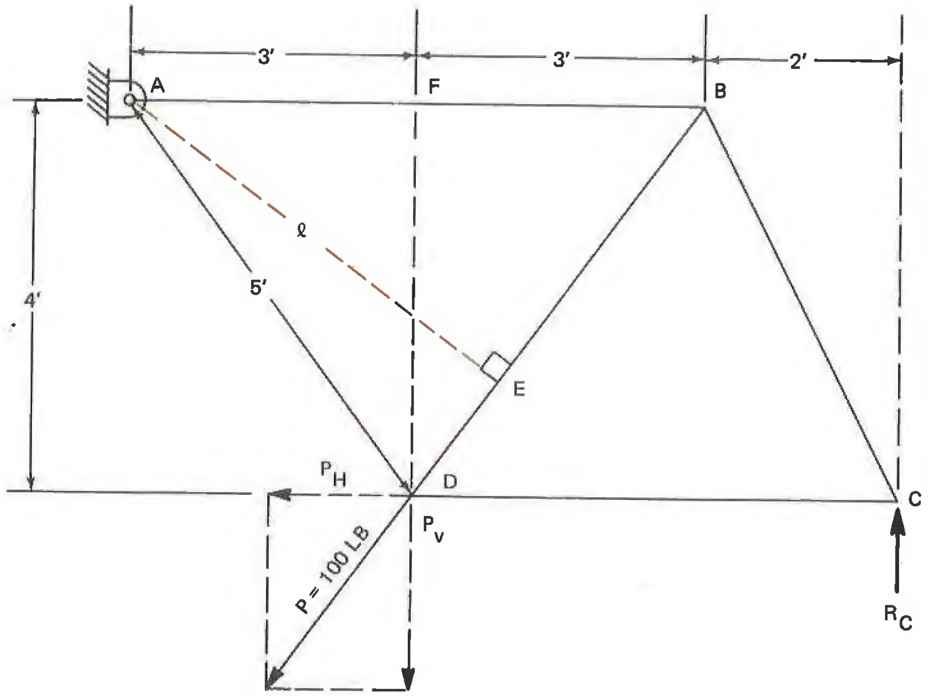


Fig. 3-3 Varignon's Theorem

$$\frac{\ell}{6} = \frac{DF}{DB} = \frac{4}{5}$$

$$\ell = \frac{24}{5} = 4.8'$$

$$M_A = P\ell = (100)(4.8) = 480 \text{ lb-ft CW}$$

According to Varignon's theorem the moment of P about A is also

$$M_A = P_V(AF) + P_H(FD).$$

Force components P_V and P_H are easily found from the geometry of the force parallelogram at D.

$$\frac{P_V}{P} = \frac{4}{5} \qquad \frac{P_H}{P} = \frac{3}{5}$$

$$P_V = 80 \qquad P_H = 60$$

$$M_A = 80(3) + 60(4) = 240 + 240$$

$$= 480 \text{ lb-ft CW}$$

In most instances you will find the second method simpler to apply than the first.

A force may be displaced anywhere along its line of action without changing any other external forces or moments. If force P were applied at point B, the moment about A would be

$$M_A = P_V(AB) + P_H(0)$$

$$M_A = 80(6) + 0 = 480 \text{ lb-ft CW}$$

The equilibrium law for forces, $\Sigma F = 0$, applies to moments of forces also. For moments this law is written

$$\Sigma M = 0 \qquad \textbf{(3.1)}$$

Equation 3.1 states that for a body in equilibrium, the algebraic sum of all moments acting on a body must be zero. **The Force law for equilibrium and the moment law for equilibrium form the basis for solving all static problems in mechanics.** They are so impor-

tant we will write them again for easy referral. Equations 3.2 will be referred to as the static

$$\overrightarrow{\Sigma F = 0}$$
$$\overrightarrow{\Sigma M = 0} \qquad (3.2)$$

equilibrium equations. In general, both the force equation and the moment equation are used together in the solution of a problem. Several examples follow.

Before the individual member loads can be found, figure 3-4, reactions R_A and R_B must be found. The moment law provides the solution. The most convenient approach is to select a point on the line of action of one of the reacting forces as the moment center. In this way the moment due to this force drops out of the equation greatly simplifying the computational effort.

Clockwise moments are generally taken as being negative, and counterclockwise moments, positive. Using this convention and summing moments about point A of the truss,

$$\Sigma M_A = 20\, R_B - 15(1000) = 0$$

$$R_B = \frac{15000}{20} = 750 \text{ lbs}$$

To find R_A, we sum moments about point E.

$$\Sigma M_E = 1000(5) - 20R_A = 0$$

$$R_A = \frac{5000}{20} = 250 \text{ lbs}$$

The equilibrium law for forces must be satisfied and provides a check on our calculations . . . taking upward forces as positive and downward forces negative,

$$R_A + R_B - 1000 = 0$$
$$250 + 750 - 1000 = 0$$
$$0 = 0$$

The reactions R_A and R_C in figure 3-5 can be found in a similar manner. To find R_C:

$$\Sigma M_A = 5R_C - 25(2400) = 0$$

$$R_C = \frac{25(2400)}{5} = 12000 \text{ lbs}$$

To find R_A:

$$\Sigma M_C = -5R_A - 20(2400) = 0$$

$$R_A = \frac{-20(2400)}{5} = -9600 \text{ lbs}$$

The negative sign on R_A is the result of assuming an incorrect direction for that reaction. Therefore, R_A is +9600 lbs acting downward. To check the work,

$$\Sigma F = 0$$
$$-R_A + R_C - 2400 = 0$$
$$-9600 + 12000 - 2400 = 0$$
$$0 = 0$$

Having found the reacting forces, the method of joints may be used to find the forces in each truss member.

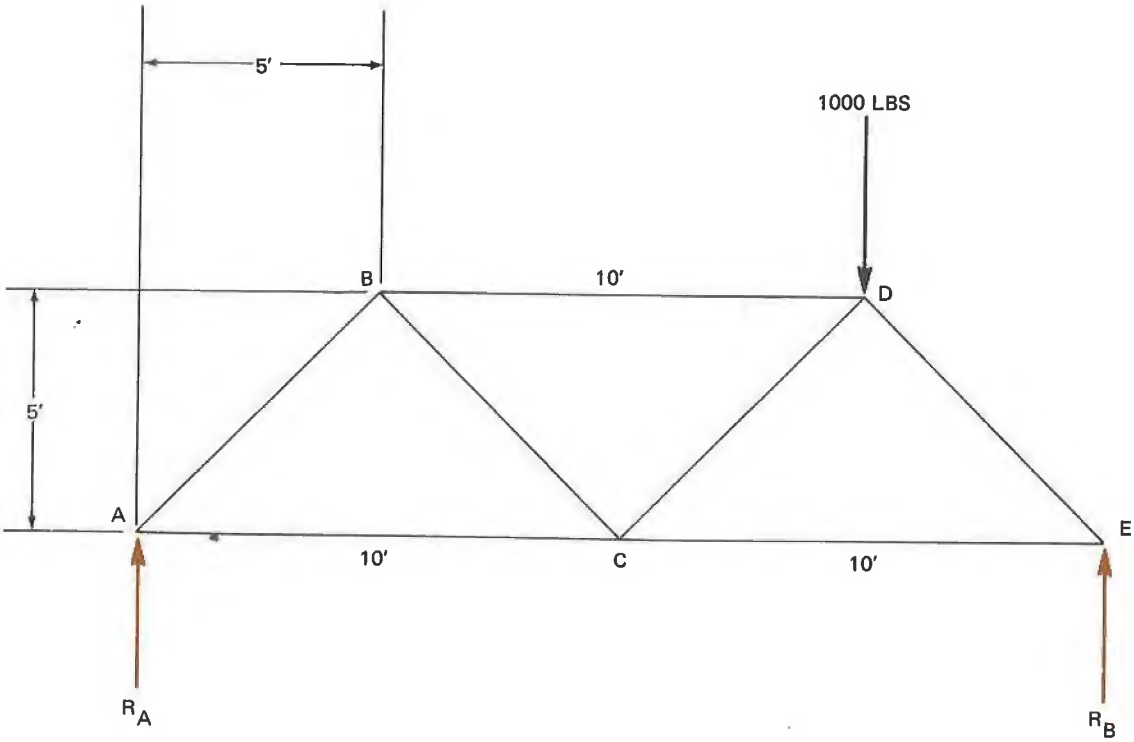


Fig. 3-4 Free Body Diagram of Eccentrically-Loaded Truss

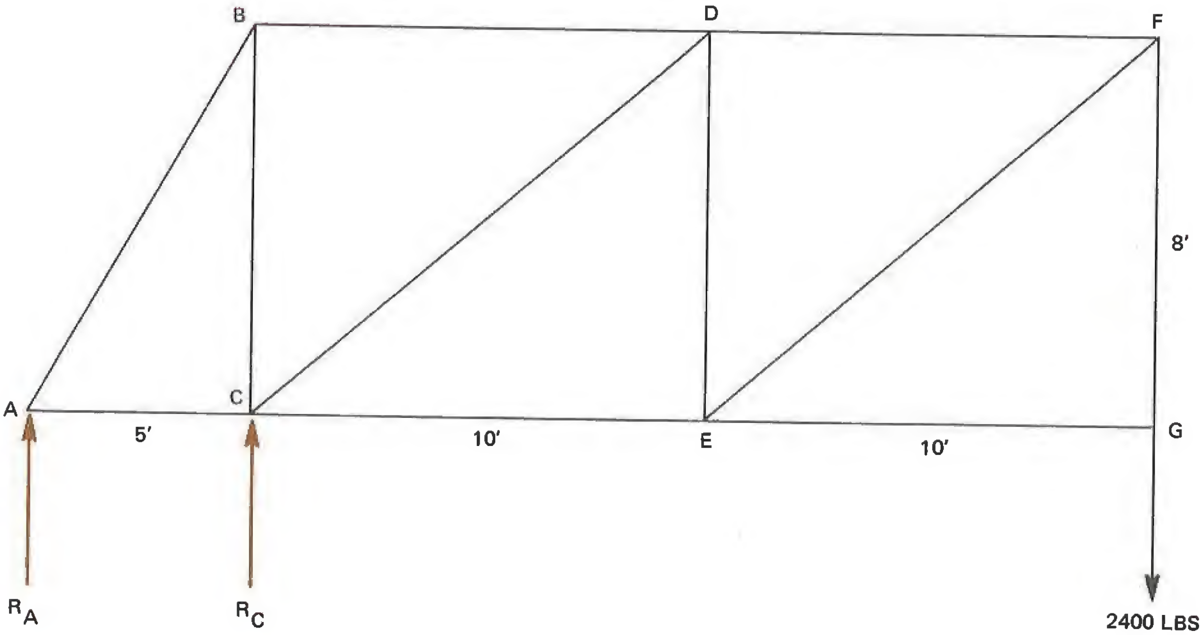
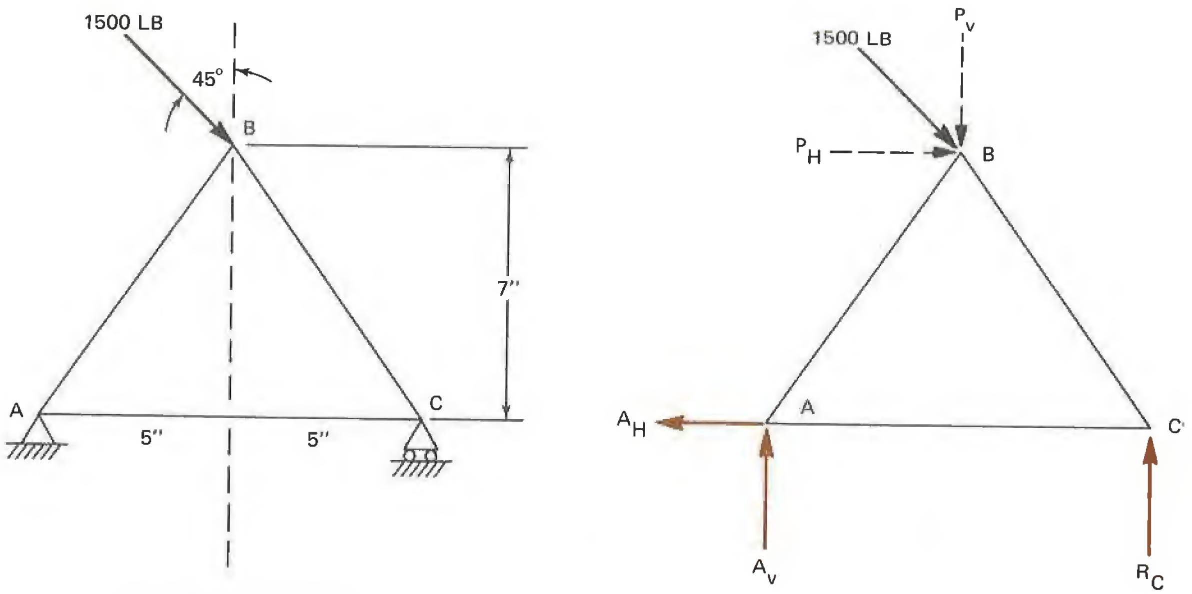


Fig. 3-5 Free Body Diagram of a Box Truss



(A) SPACE DIAGRAM *(B) FREE BODY DIAGRAM*

Fig. 3-6 Triangle Truss with Angle Load

The triangle truss is shown with roller support in the space diagram. **If we did not indicate a roller support this problem could not be solved by methods of statics. Two solid supports would each carry some of the horizontal component of the load. The relative amounts would be unknown and the structure would be said to be statically indeterminate. Many actual structures are built with roller or flexible supports to allow for such things as thermal expansion. The roller permits free expansion and eliminates excessive stress and perhaps failure due to buckling.**

Note that the reaction at A is shown in terms of its two components—the vertical component A_V and the horizontal component A_H. Using moments we will find the magnitude of these components from which the reacting force R_A can be found. To begin the solution we find the force components P_V and P_H. Knowing the direction of the load,

$$P_V = 1500 \cos 45° = 1500(0.707) = 1060 \text{ lbs}$$

$$P_H = 1500 \sin 45° = 1500(0.707) = 1060 \text{ lbs}$$

$$\Sigma M_c = P_V(5) - P_H(7) - A_V(10) + A_H(0) = 0$$

$$A_V = \frac{(1060)(5) - (1060)(7)}{10} = -212 \text{ lbs}$$

The negative sign for A_V indicates that the direction assumed for A_V was incorrect. A_V is 212 lbs acting downward.

Both R_C and A_H may be found from the force equilibrium equation. For vertical forces,

$$\Sigma F_V = -P_V - A_V + R_C = 0$$

$$R_C = 1060 + 212$$

$$R_C = 1272 \text{ lbs}$$

For horizontal forces,

$$\Sigma F_H = -A_H + P_H = 0$$

$$A_H = P_H$$

$$A_H = 1060 \text{ lbs}$$

Let's use moment equilibrium about B as a check on our work.

$$\Sigma M_B = R_c(5) + A_v(5) - A_H(7) = 0$$

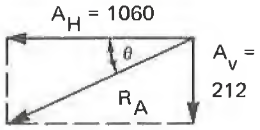
$$1272(5) + (212)(5) - (1060)(7) = 0$$

$$6360 + 1060 - 7420 = 0$$

$$7420 - 7420 = 0$$

$$0 = 0$$

The magnitude and direction of R_A is now found.



$$R_A = \sqrt{(1060)^2 + (212)^2}$$

$$= \sqrt{117 \times 10^4} = 1080 \text{ lbs}$$

$$\theta = \tan^{-1} \frac{212}{1060} = \tan^{-1} 0.2 = 11.3^\circ$$

An alternate method to the analytical technique illustrated above is the use of the String Polygon method. It is a graphical technique best described by example. The truss of figure 3-7 will be used in this example.

The space diagram and the free body diagram are first drawn carefully to scale. Select an appropriate force scale and begin constructing a force polygon by carefully drawing the applied force vectors B and C. Note that vectors are labeled according to their point of application. A pole point for the force polygon is now selected. It may be located either to the right or left of the force polygon. Its placement should be such that rays from the pole to the vector extremities do not have a steep slope.

The force polygon now contains two known vectors and **must close** when the reacting forces are added to complete the polygon. The direction of the reaction at D is known because there is a roller support at D. This reaction force must be perpendicular to the plane of rolling. The direction of R_A is unknown at this point.

Inspection of the force polygon shows that applied force B has components given by rays A-B and B-C. And force C has components B-C and C-D. The intermediate compo-

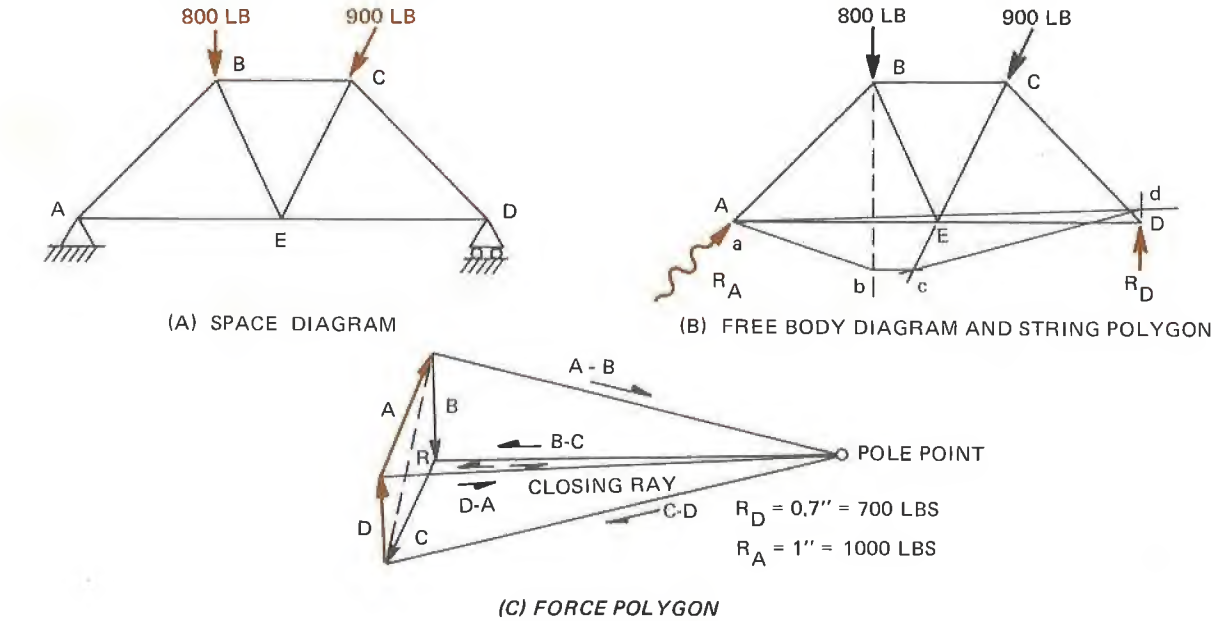


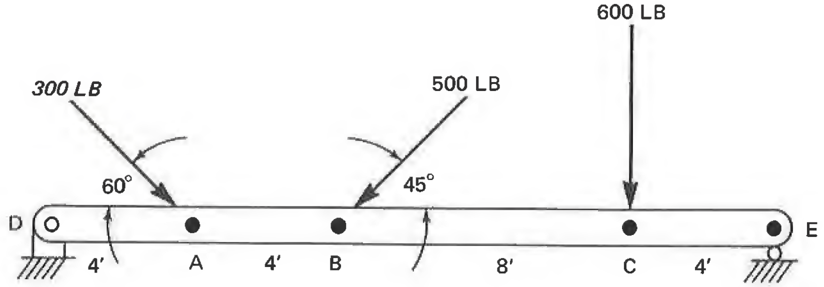
Fig. 3-7 String Polygon Method for Determining Reactions

nents B-C are in opposing directions, i.e., they are self-cancelling, leaving a resultant applied force R with components A-B and C-D. For equilibrium, reactions A and D must exactly cancel R. Reaction D has components C-D and D-A. Reaction A has components D-A and A-B. The ray D-C defines the intersection of reacting forces D and A. It is found from the string polygon.

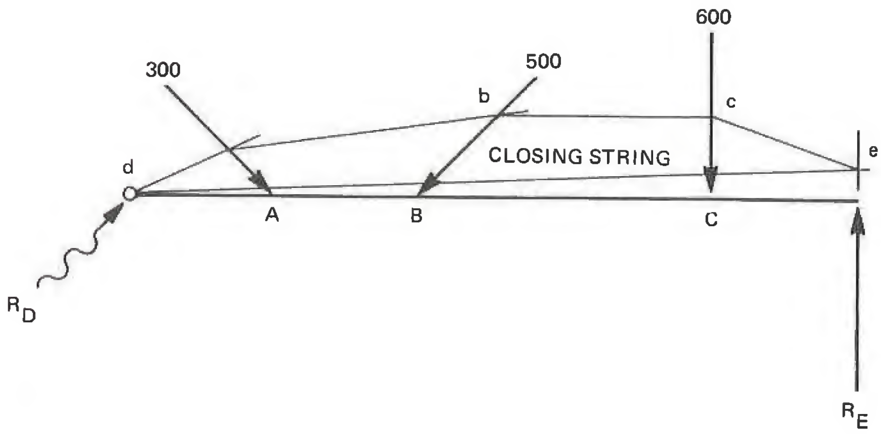
The string polygon is constructed by transferring the direction of the rays from the force polygon to the free body diagram. The length of any string is determined by its intersection with two lines of action.

In this problem the direction of R_A is initially unknown. The buckled arrow shaft indicates this. All strings are drawn between lines of action. R_A acts at A so point A is the only known location of the line of action of this force. It is necessary then that the string polygon start at A. Strings a-b, b-c, and c-d are drawn with directions taken from the force polygon and lengths determined by their intersection with the lines of action of each force. The string polygon must close just as the force polygon closes. **This establishes a closing string d-a.** The direction of d-a establishes the closing ray on the force polygon finally establishing reactions D and A.

A second graphical example is shown in figure 3-8.



(A) SPACE DIAGRAM



(B) FREE BODY DIAGRAM AND STRING POLYGON

Fig. 3-8 Reactions on Loaded Beam Using the String Polygon

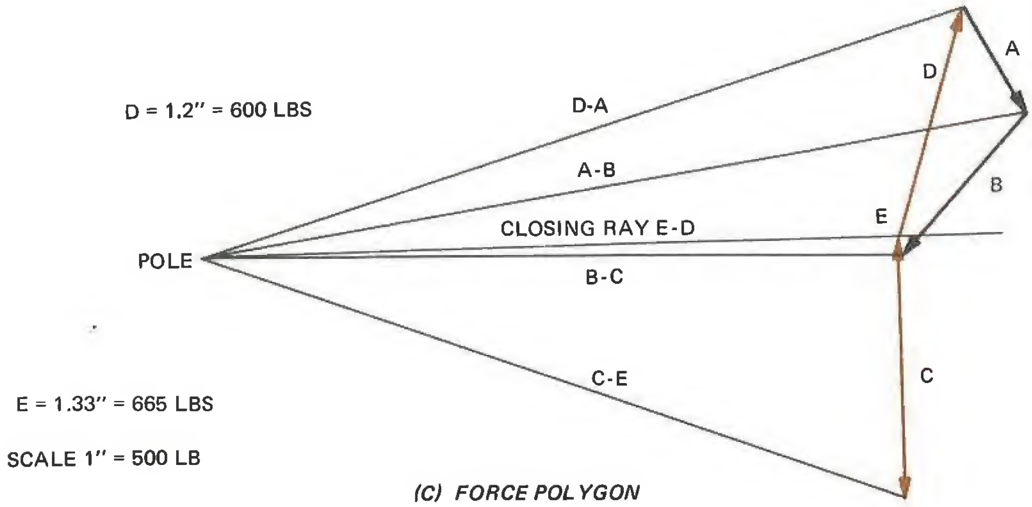


Fig. 3-8 Reactions on Loaded Beam Using the String Polygon (Cont'd)

MATERIALS

1 Loading frame with 2-1/2 in. diameter hydraulic load cylinder
2 Ring force transducers
11 4-1/2 in. links
14 Joint connectors
1 1-in. link connector
1 6-in. rigid connector
1 Box of 1/4 in. pins

PROCEDURE

1. Inspect apparatus for proper working order.
2. Assemble the truss shown in figure 3-9. Use one ring transducer and one 6 in. rigid connector to connect the truss to the lower frame rail.

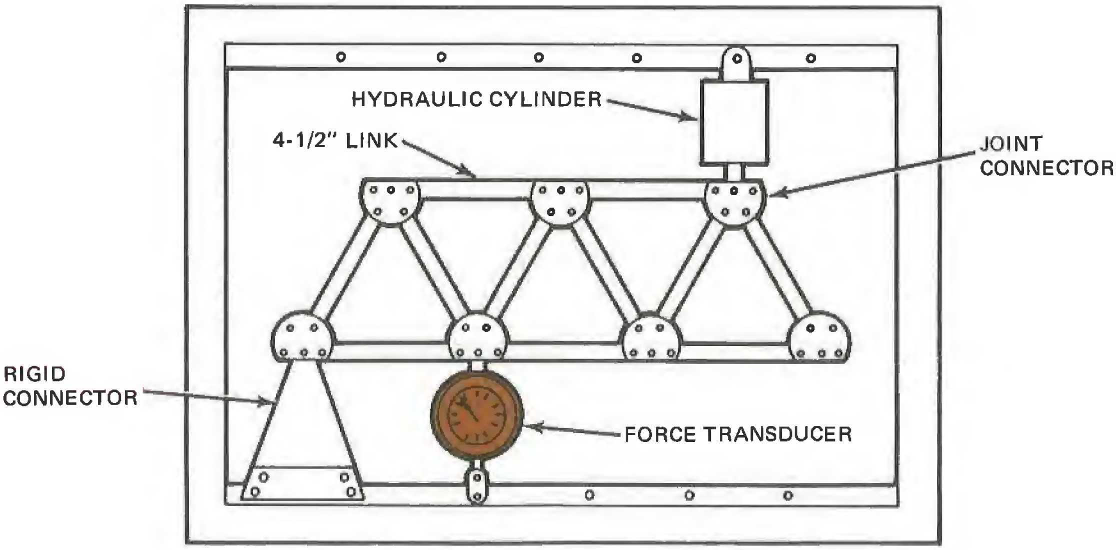


Fig. 3-9 The Experimental Setup

3. Assume a downward load of 500 pounds applied at joint F. Calculate the reacting forces and use the method of joints to solve for the force in each member.

4. Place a 500-pound downward load on the truss with the hydraulic cylinder. Read the reacting force, unload, interchange the rigid connector and force transducer load and read the other reacting force. Record these forces.

5. Use one rigid link and one simple link to support the truss. Systematically replace every line, two at a time, with the ring transducers, load the truss and record each link force.

ANALYSIS GUIDE. Do the measured values of the reactions satisfy both the force and moment equilibrium laws? Construct a force summation diagram and show predicted and calculated values for the forces in each truss member.

Force Transducer #1 k =

Transducer Position	Deflection Δ	Force, lbs P	Hyd. Press p	Piston Area A	Load, lbs

Fig. 3-10 The Data Tables

Force Transducer #2 k =

Transducer Position	Deflection Δ	Force, lbs P	Hyd. Press P	Piston Area A	Load, lbs

Fig. 3-10 The Data Tables (Cont'd)

PROBLEMS

1. Calculate the maximum permissible load on this truss when loaded and supported in the configuration of this experiment if the allowable stress in each member is 30,000 psi. (Assume the joints are strong enough to support this load without failing.)
2. Find the reactions for the truss shown in figure 3-11 using the analytical method.

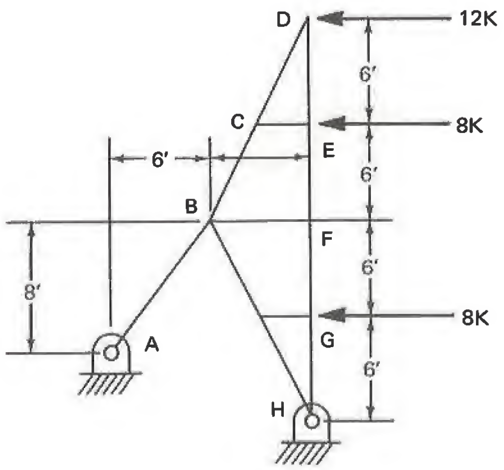


Fig. 3-11 Truss for Problem Two

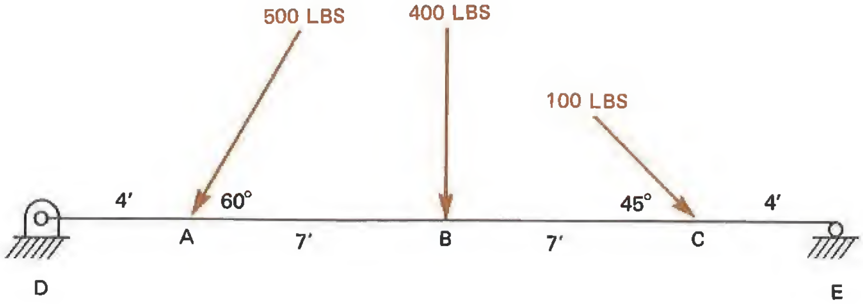


Fig. 3-12 Problem Three

3. Solve figure 3-12 for the reactions at D and E by using the string polygon method.
4. Solve for the reactions at D and E in problem three using the analytical method.

experiment 4 *MECHANICAL PROPERTIES OF MATERIALS*

INTRODUCTION. The proper selection and use of materials depends on a knowledge of material properties. In this experiment we will study some of the mechanical properties of materials.

DISCUSSION. Materials are described in terms of their properties. To completely describe all the properties of any given material would indeed require a great effort.

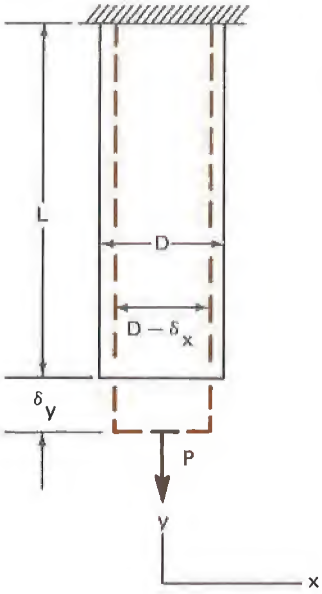
We would have to list physical, chemical, thermal and mechanical properties, for example. The table in figure 4-1 is a partial classification of properties of engineering materials. Undoubtedly, other classes and properties could be added.

The use to which a material is put will dictate which of the many properties is most important. An acid bath tank would certainly require looking at the corrosion characteristics, while a shaft design would involve the endurance to fatigue as one of the most important properties.

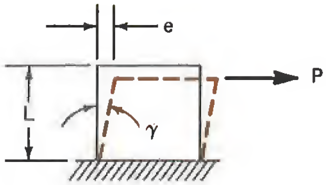
In this experiment we will obtain some of the mechanical properties of various materials. Mechanical properties always involve

Class	Properties in this Class	Class	Properties in this Class
Physical	Geometry		Toughness
	Density		Hardness
	Porosity		Lubricity
	Microscopic Structure		Poisson Effects
	Macroscopic Structure		Brittleness
	Moisture Content	Thermal	Conductivity
Chemical	Acidity or Alkalinity		Specific Heat Capacity
	Molecular Bonding		Diffusivity
	Corrosion Characteristics		Expansivity
	Composition	Electrical	Conductivity
Mechanical	Strength:	Magnetic	Magnetic Permeability
	Tension		Galvanic Activity
	Compression	Acoustic	Sound Transmissibility
	Flexure		Surface Absorptivity and
	Shear		Reflectivity
	Impact	Optical	Color
	Endurance to Fatigue		Reflectivity
	Elasticity		Absorptivity
	Resilience		Transmissibility
	Ductility		

Fig. 4-1 Classification of the Properties of Engineering Materials



(A) TENSION



(B) SHEAR

Fig. 4-2 Load and Deformation in Tension and Shear

measurement of stress or strain or stress and strain together. Deformations from which strain can be calculated are shown in figure 4-2 for tension and shear.

Note that the tensile specimen deforms both in the direction of the load and also transverse to the load. The strain in the direction of the load is called normal strain and is calculated from

$$\epsilon_y = \frac{\delta_y}{L} \qquad (4.1)$$

Equation 4.1 defines the normal strain as the ratio of elongation to original length. This is the unit normal strain and is a dimensionless quantity (inches/inch).

The lateral deformation shown is Poisson deformation and Poisson strain in this case is

$$\epsilon_x = \frac{\delta_x}{L} \qquad (4.2)$$

Poisson strain is strain which occurs without stress. In this case there is no load or stress applied in the x direction. The Poisson effect is readily observed by stretching a rubber band and noting how it shrinks in the lateral direction. The ratio of longitudinal strain to Poisson strain is Poisson's Ratio, μ.

$$\mu = \frac{\epsilon_x}{\epsilon_y} \qquad (4.3)$$

Poisson's ratio is a mechanical property of a material and as such will be listed in handbooks. You should be careful to differentiate between a material property, i.e. a fixed quantity for the material, and parameters such as stress or strain which occur due to a given load.

Some materials are isotropic: This means the material properties are uniform in every direction within the material. There are exceptions to this. The most notable non-isotropic material is wood. Mechanical prop-

erties of wood must be listed separately for parallel and across grain.

The load pulling the tension member in figure 4-2 causes a normal stress given by

$$s = P/A \qquad \textbf{(4.4)}$$

In all materials there is a proportionality between stress and accompanying strain, i.e.,

$$s \cong \epsilon \qquad \textbf{(4.5)}$$

In many materials the proportionality is linear up to some limiting value of stress (or strain). This linear relationship is often referred to as Hooke's Law. The constant of proportionality is called the modulus of elasticity and is also called Young's Modulus in honor of the physicist who first defined it. The symbol for modulus of elasticity is E and the proportionality of 4.5 can be written as the equation

$$\boxed{s = E\epsilon} \qquad \textbf{(4.6)}$$

For steel E is about 30,000,000 psi. Suppose you were to load a steel bar one square inch in cross section and 60 inches long with a tensile force of 30,000 pounds. What would be the strain and the total elongation?

$$s = \frac{P}{A} = \frac{30000}{1} = 30{,}000 \text{ psi}$$

$$\epsilon = \frac{s}{E} = \frac{3 \times 10^4}{3 \times 10^7} = 0.001 \text{ in./in.}$$

$$\delta = \epsilon L = (0.001)\,(60) = 0.06 \text{ inches}$$

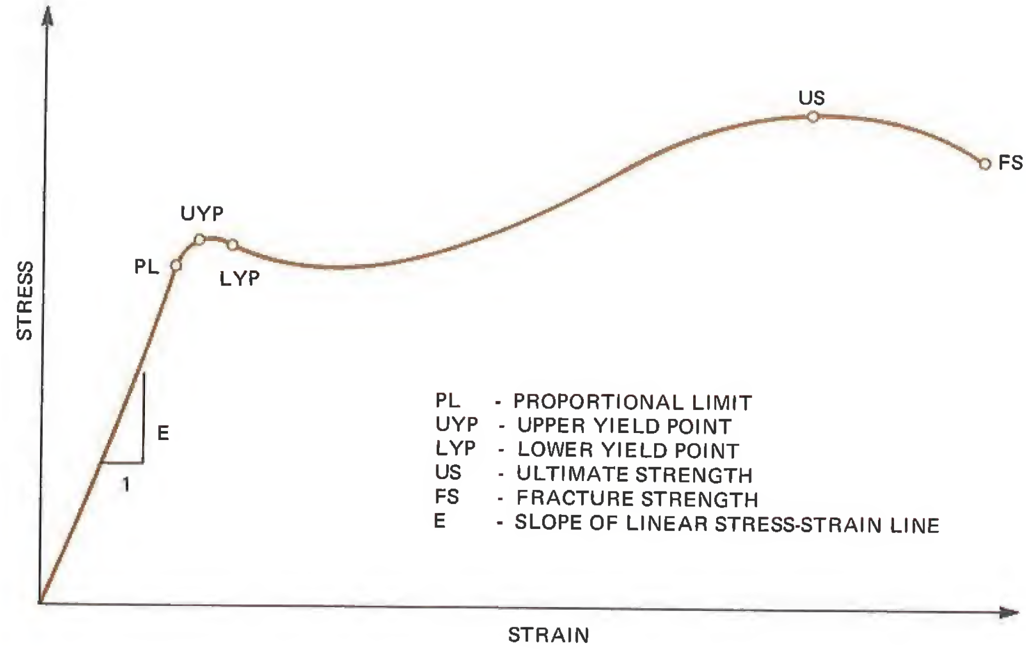
Modulus of elasticity is a measure of the stiffness of a material. Only a few of the "exotic" materials have a modulus of elasticity greater than steel. All other materials are considerably less "stiff". The table in figure 4-3 lists E for a few common materials.

Materials	E in psi
Steel	30,000,000
Gray Cast Iron	14,000,000
Wrought Iron	27,000,000
Copper	16,000,000
Nickel	30,000,000
Zinc: Cast	11,000,000
Hardrolled	12,000,000
Aluminum:	
Sandcast	9,000,000
Annealed Sheet	10,000,000
Hard Sheet	10,000,000
Brass	12,000,000
Concrete	2 - 5,000,000
Plastics:	
Phenol formaldehyde compounds	7.5 - 1,000,000
Wood: (parallel to grain)	
Douglas Fir (coast)	1,920,000
Redwood	1,340,000
Hickory	2,180,000

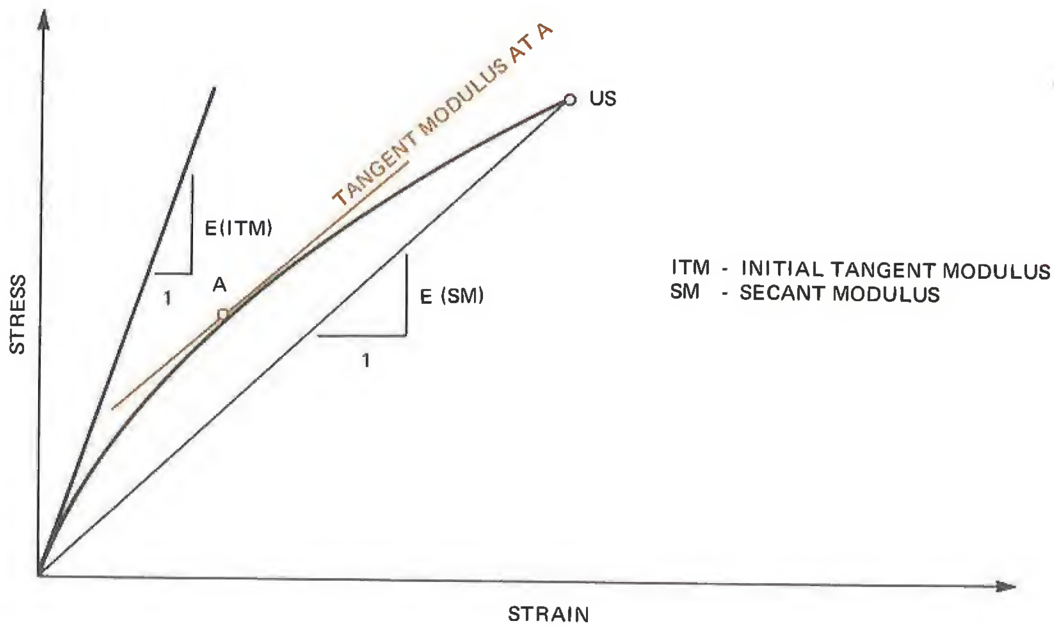
Fig. 4-3 Modulus of Elasticity for Several Common Materials

The stress-strain relationships show unique characteristics for brittle and ductile materials. You can think of the stress-strain diagram as the "fingerprint" of the material. Figure 4-4A shows a stress-strain diagram for a ductile material and figure 4-4B, for a brittle material.

Most ductile materials exhibit very linear stress-strain behavior up to a point called the proportional limit. **Equation 4.6 is valid only up to this point.** Further stress will take the



(A) DUCTILE MATERIAL



(B) BRITTLE MATERIAL

Fig. 4-4 Typical Stress-Strain Diagrams

material to the yield point. A very ductile material will show an upper yield point followed by a decrease in stress to a lower yield point. Material taken to the yield point will have a permanent set when the load is released. This set is a measure of plastic deformation. A soft steel specimen will elongate about 20% before fracture. Soft plastics such as polyethylene have a near endless elongation. As long as a ductile material is not stressed above its yield point, it will essentially return to its original size and shape upon release of the load. This ability to return to original dimensions is a measure of the elasticity of the material. You might note that modulus of elasticity is somewhat of a misnomer. It is really a measure of material stiffness.

The brittle materials show a markedly different stress-strain curve (figure 4-4B). This curve is quite representative of materials such as concrete and cast iron. There is no truly linear portion in the stress-strain diagram, and no definite yield point. When this material is stressed, it apparently suffers continuous local yielding at a microscopic level for all force levels. The strain is a measure of this accumulated local yielding.

There are several ways of reporting modulus of elasticity for this kind of material:

1. **Initial Tangent Modulus** – After constructing the stress-strain diagram, a straight line is carefully drawn tangent to the curve at the origin. The slope of this line is the Initial Tangent Modulus.

2. **Secant Modulus** – A straight line is drawn from the origin of the stress-strain diagram to some other point on the curve. The slope of this line is the secant modulus. The secant modulus at the ultimate strength is shown on figure 4-4B.

The tangent modulus and secant modulus may be calculated for any point on the stress-strain curve.

Most materials are not ideally ductile nor brittle as shown in figure 4-4. When a definite yield point does not exist, the offset method may be used for establishing a yield point as shown in figure 4-5.

A typical material, stressed to point A will follow a path near to AB when unloaded.

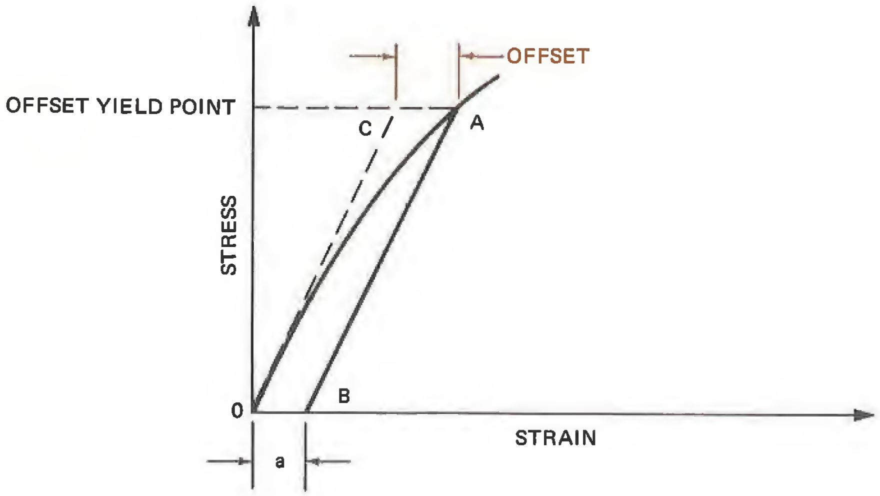


Fig. 4-5 Yield Point by the Offset Method

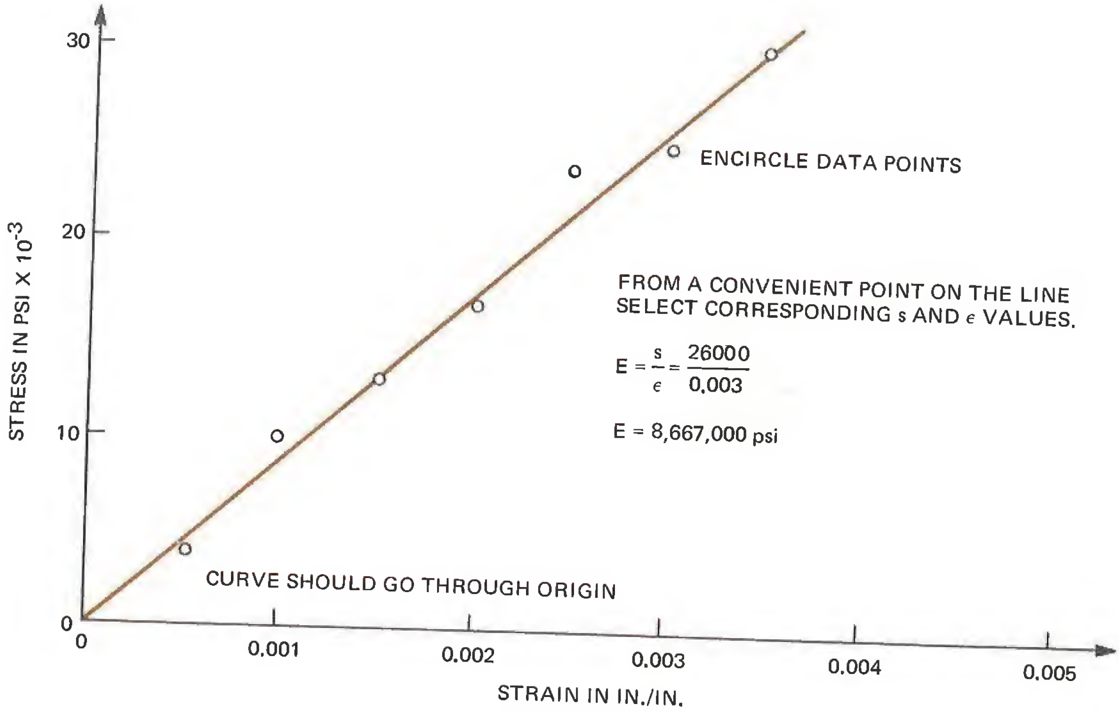


Fig. 4-6 Determining Modulus of Elasticity

The permanent set is indicated by a. This set will be practically the same as the offset CA. Line BA is constructed on the stress-strain diagram to be parallel to the initial slope OC of the stress-strain curve OA. The intersection A of these two lines establishes the yield strength by the offset method.

Values of a in common use for metal are 0.001 and 0.002 (0.1 and 0.2 percent strain per inch of gage length). For cast iron, values range from 0.0002 to 0.0005 and for concrete, 0.0001 and 0.0002.

Elongations experienced during the tensile test are small and great care must be taken to insure accurate results. **Data should be plotted as shown in figure 4-6 with the best smooth curve or straight line drawn in to fit the data. The value for modulus of elasticity should always be computed by finding the slope of this best line or of a tangent line or secant line for the brittle material.**

MATERIALS

1 Loading frame with 2-1/2 in. diameter hydraulic load cylinder
1 Dial indicator, 0.0001 in. per division
1 Extensometer bracket
1 Soft steel specimen
1 Aluminum specimen 2024 ST
1 Plastic specimen
2 Specimen connectors

PROCEDURE

1. Inspect apparatus for proper working order. The dial indicator must have a free and smooth movement.

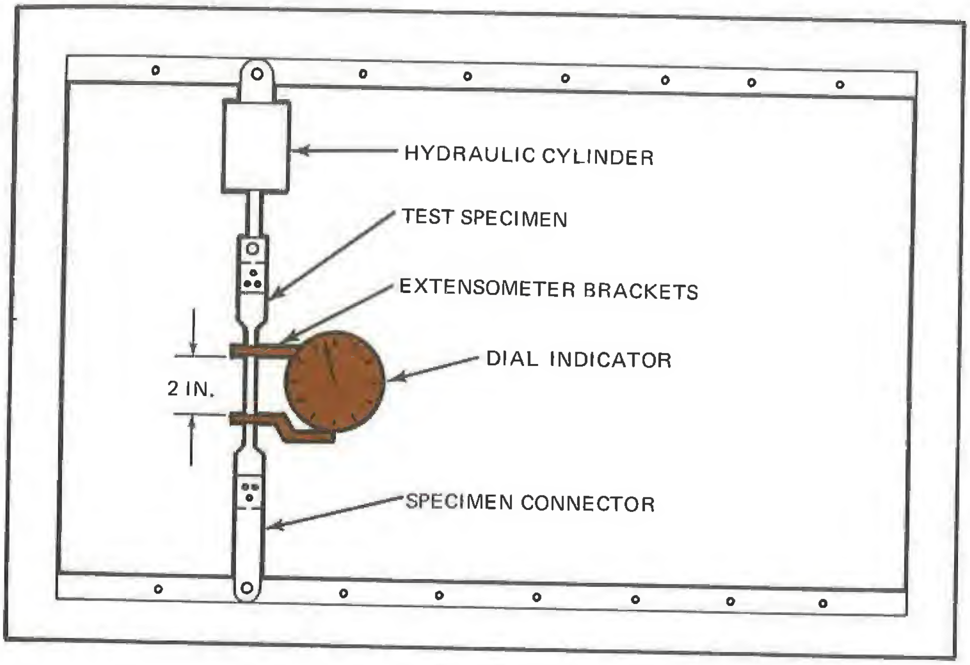


Fig. 4-7 The Experimental Setup

2. Carefully measure the width and thickness of the test specimen with a micrometer and record.

3. Place specimen in load frame as shown in figure 4-7. Fasten extensometer brackets on central portion of the first test specimen so the test length is exactly two inches. Attach dial indicator and zero the reading.

4. Put a tensile load on each specimen. Load slowly and carefully, stopping only if necessary to obtain readings. Read and record extension and accompanying load in increments of 0.0002 for steel, 0.0005 for aluminum, 0.0050 for plastic. Stop loading when s = 30,000 psi for steel and aluminum, 5000 psi for plastic. Unload and record zero load.

ANALYSIS GUIDE. We know the stress-strain diagram must go through the origin. If yours does not, it is because of experimental error such as incorrect zero of the extensometer, blending of the specimen, etc. Inspect each stress-strain diagram for linearity. Did any specimen have any permanent set? How do your values compare with published data?

Specimen	Width	Thickness	Area

Fig. 4-8 The Data Table

Elongation δ	Strain ϵ	Hyd.Press ρ	Hyd Cyl Area A_c	Load P	Specimen A	Stress s

Fig. 4-8 The Data Table (Cont'd)

PROBLEMS

1. Calculate Poisson's ratio if

$$\epsilon_y = 0.0018$$

$$\epsilon_x = 0.00049$$

2. Show that for a uniform bar in tension, the total elongation, δ, due to load P is

$$\delta = \frac{PL}{AE}$$

3. What errors will be present in elongation data if the specimen is not loaded with perfect axial alignment of the specimen connectors? Show this in a sketch.

4. A copper wire with 0.125-inch diameter and 100 feet long is pulled in tension. Careful measurements show the loaded length to be 100.25 feet. Calculate the tensile load P in the wire.

5. For the data given in figure 4-9 find:

   (a) The Initial Tangent Modulus.
   (b) The Secant Modulus for a stress level of 30,000 psi.
   (c) The yield strength by the offset method for a 0.0001 offset.

Stress, psi	Strain, in./in.
8000	0.0001
15500	0.0002
21000	0.0003
25500	0.0004
29500	0.0005
32500	0.0006

Fig. 4-9 Problem Data

experiment 5 TENSION TEST OF SOFT STEEL

INTRODUCTION. The tension test is the basic test for determining the mechanical properties of materials. In this experiment, we will perform a complete test on soft steel.

DISCUSSION. Steel with a carbon content of 15-20 points (0.15 to 0.2%) is a commonly used structural material. It is ductile and should have a stress-strain diagram similar to that of figure 5-1. One way to call out this material is AISI C1015 for 15 point carbon. AISI refers to the American Iron and Steel Institute. The American Society for Testing Materials (ASTM) uses a different callout numbering scheme. Steel with 20 points or less of carbon is generally referred to as soft steel or mild steel or low carbon steel.

The elongation of the specimen after yielding is so much greater than before, the strain axis on the stress-strain diagram is normally scaled twice as shown in figure 5-1. A small scale is used for the elastic region. In this way the slope from which E is found, and the yield points are clearly shown. The coarse scale shows behavior in the plastic region up to failure.

The properties indicated in figure 5-1 are normally reported in terms of the Unit Stress. Areas under the stress-strain diagram also pro-

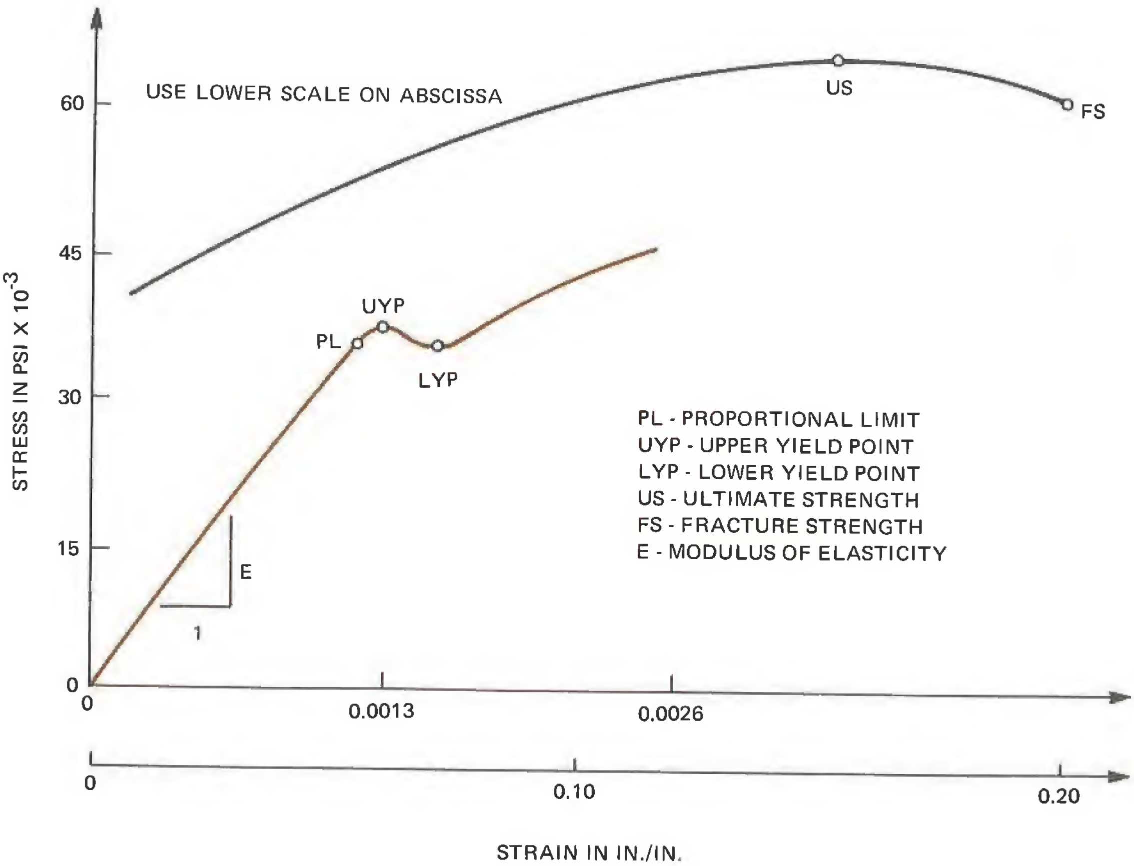


Fig. 5-1 Stress-Strain Diagram for Low Carbon Steel

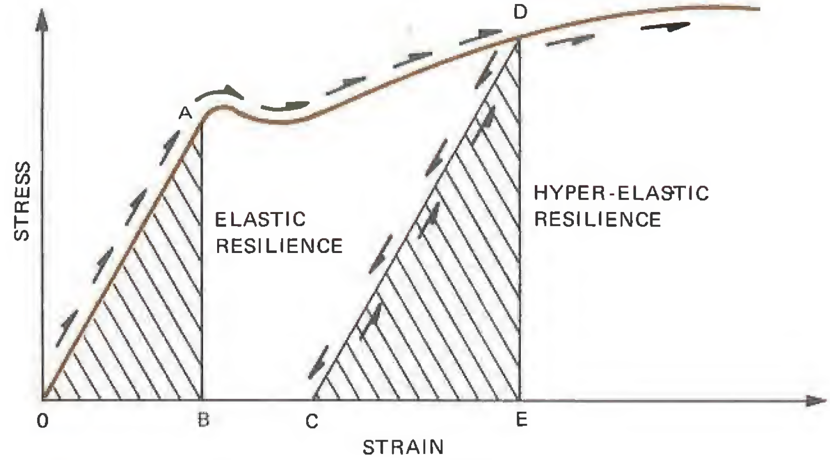


Fig. 5-2 Areas of Resilience

vide valuable information about the material behavior. Figure 5-2 illustrates areas that define the material's resilience.

The area OAB represents the elastic or strain energy stored in each cubic inch of material. This is equivalent to the work done by the forces which deformed the specimen. Strain energy is given the symbol U.

$$U = Wk = \int s d\epsilon$$

But

$$s = E\epsilon$$

So

$$\boxed{U = \int E\epsilon d\epsilon = \frac{E\epsilon^2}{2} = \left[\frac{lb}{in.^2}\,\frac{in.}{in.} = \frac{lb\text{-}in.}{in^3}\right]} \quad (5.1)$$

The strain energy may be variously written as in equation 5.1 or

$$\boxed{U = \frac{E\epsilon^2}{2} = \frac{s}{\epsilon}\frac{\epsilon^2}{2} = \frac{s\epsilon}{2}\left[\frac{lb\text{-}in.}{in.^3}\right]} \quad (5.2)$$

$$\boxed{U = \frac{s\epsilon}{2} = \frac{s}{2}\frac{s}{E} = \frac{s^2}{2E}\left[\frac{lb\text{-}in.}{in.^3}\right]} \quad (5.3)$$

Each of the strain energy formulas has the units of lb-in./in.^{3} or energy per cubic inch. This stored energy can be retrieved by allowing the internal stresses in the material to pull back the applied load until all the forces return to zero.

The modulus of resilience is an important property to consider for mechanical springs. The spring must repeatedly store and release strain energy so a material with a large modulus of resilience would be the most effective for this application.

We know from experiment that a specimen loaded to point D (figure 5-2) and then unloaded would follow a line DC. Line DC is parallel to AO. If the specimen is reloaded it will again follow path CD. Thus, even after considerable plastic deformation, if the specimen is unloaded it will behave again as if it were elastic. When the specimen is reloaded it will exhibit a yield point somewhat higher than the initial yield. The second yield will

also have a more brittle character. This is a work hardening effect. The same hardening and strengthening effect occurs when the material is cold rolled or cold worked in the process of production.

Another example of material that has strong work hardening characteristics is copper. A few bends in an initially soft annealed copper can cause the material to harden and crack if worked sufficiently.

Toughness defines the ability of a material to absorb loads up to the fracture point. The total area under the stress-strain curve represents the energy-absorbing capabilities of the material from the start of loading up to fracture. Material which might be subjected to impact or shock loading is very apt to be stressed above its yield point. The modulus of toughness will be a good indicator of its ability to take this load without failing. Railroad car couplings serve as one example of an application requiring a tough material. The area of the elastic resilience is very small compared to the area showing toughness in ductile materials. A brittle material does not have the large area afforded by the plastic deformation of a ductile material. This is why a brittle material is of little value in impact load conditions. Glass, for example, is basically a strong material, but its extreme brittleness precludes its use where high energy loads might be involved. The relative toughness of different carbon steels and cast iron is shown in figure 5-3.

Unit stress is described in two ways and only two ways. One way is as a normal stress and the second is as a shear stress. It is important to understand these two stresses in order to appreciate what is happening in the tensile specimen.

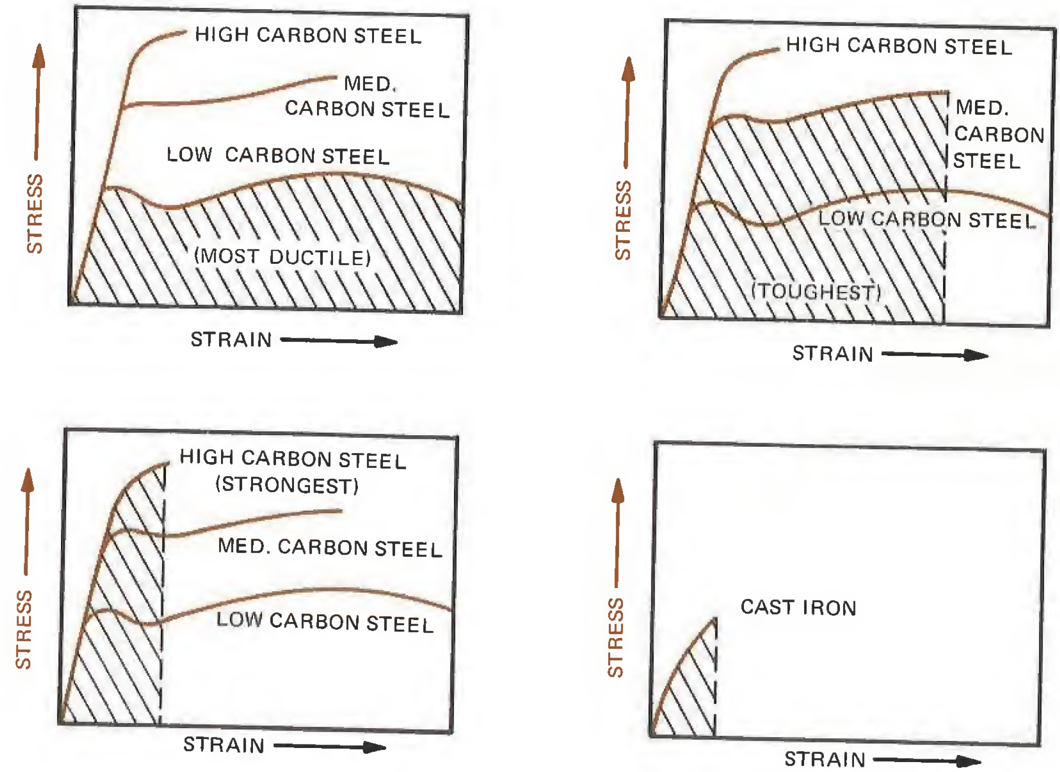


Fig. 5-3 Modulus of Toughness for Different Carbon Steels and Cast Iron

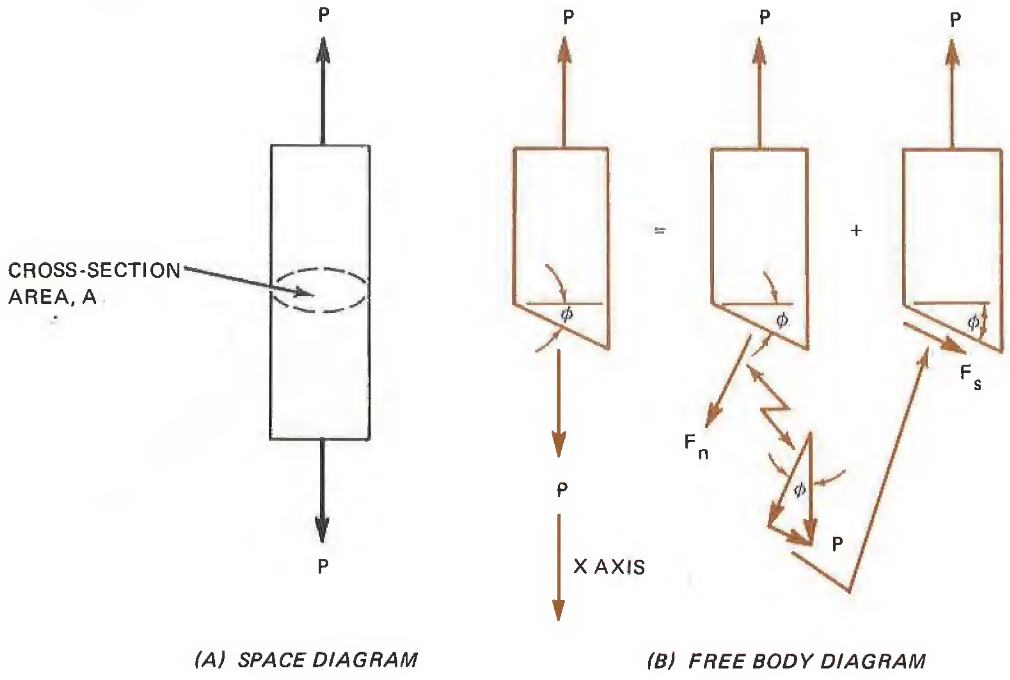


Fig. 5-4 Normal and Shear Forces in a Tensile Specimen

The free body diagram of figure 5-4 shows the normal force F_n and the shear force F_s needed to provide force equilibrium. Why the free body of a slanting section? Because stress is directional (a vector) and if we are to understand the stresses in the material we must look at every possible situation. In this case we discover that a simple tensile specimen experiences not only normal (tensile) stress but also shear stress on slanted planes.

From the force polygon the normal and shear forces are

$$\boxed{\begin{aligned} F_n &= P\cos\phi \\ F_s &= P\sin\phi \end{aligned}} \qquad (5.4)$$

When $\phi = 0$, normal stress s is in x direction. We use the x axis as a reference direction. Thus, when $\phi = 0$, we say

$$s = s_x$$

Calculation of normal stress (s_n):

$$s_n = \frac{P\cos\phi}{A_{slant}}$$

$$A_{slant} = A/\cos\phi$$

$$s_n = \frac{P\cos\phi}{A/\cos\phi} = \frac{P}{A}\cos^2\phi$$

But

$$\frac{P}{A} = s_x$$

$$s_n = s_x\cos^2\phi \qquad (5.5)$$

Calculation of shear stress (s_s):

$$s_s = \frac{F_s}{A_{slant}} = \frac{P\sin\phi}{A/\cos\phi}$$

$$s_s = \frac{P}{A}\sin\phi\cos\phi$$

$$s_s = s_x\frac{\sin 2\phi}{2} \qquad (5.6)$$

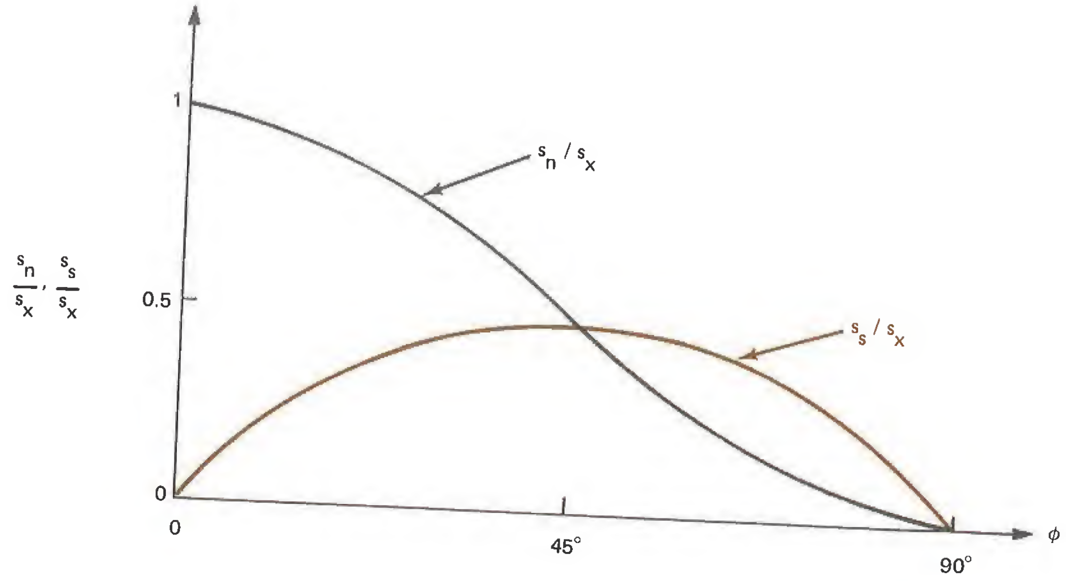


Fig. 5-5 Normal and Shear Stress on Slant Planes

With equations 5.5 and 5.6 the amount of shear and normal stress may be calculated for any angle ϕ. If we plot s_n/s_x and s_s/s_x vs ϕ on the same graph, the relative amounts of shear stress and normal stress on the various slant planes are observable at a glance.

From figure 5-5 we observe the maximum shear stress is one-half of the maximum normal stress. This maximum shear stress occurs on planes 45° to the load, and shear and normal stress are equal on these planes.

The character of the fracture plane in a tensile specimen gives us indications about the material's ability to resist stress. A cast iron specimen, for example, always has a fracture plane perpendicular to the load (ϕ=0). This must be a pure tensile separation and we know this material is able to withstand the shear stress imposed on it. Soft steel, on the other hand, shows a more complex fracture plane. Round steel specimens have a fracture commonly called a cup-cone. The sides of the cup and cone are about 45°. This indicates that failure occurred on planes of maximum shear stress and that ductile steel is weaker in shear than in tension. Since the maximum shear stress in the tensile specimen is one-half that of the tensile stress, shear strength of steel is taken as one-half of its reported tensile strength. This can be verified fairly accurately by a shear test.

MATERIALS

- 1 Loading frame with 2-1/2 in. diameter hydraulic load cylinder
- 1 Dial indicator, 0.0001 in. per division
- 1 Extensometer bracket
- 1 Soft steel tensile specimen
- 2 Specimen connectors
- 1 Divider
- 1 Machinist scale

PROCEDURE

1. Inspect apparatus for proper working order. The dial indicator must have a free and smooth movement.

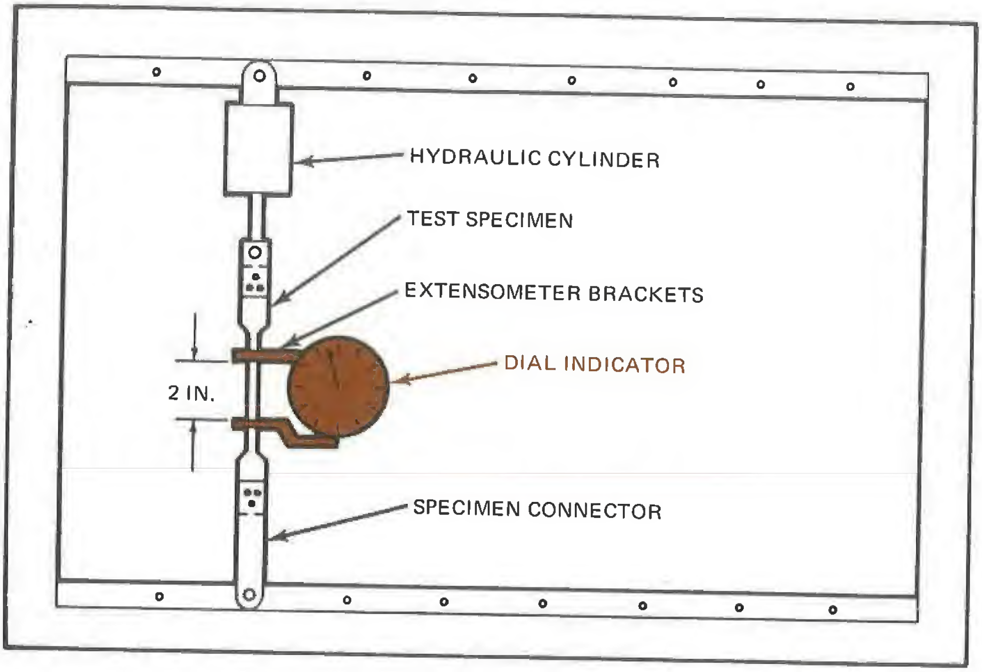


Fig. 5-6 The Experimental Setup

2. Carefully measure the width and thickness of the specimen with a micrometer and record.
3. Mark a 2 in. gage length in the center of the specimen with light punch marks.
4. Place specimen in the load frame as shown in figure 5-6. Fasten extensometer brackets to align with the punch marks. Zero the dial indicator.
5. Slowly load the specimen stopping only if necessary to take readings. Read extension and load in increments of 0.0002 extension up to yield.
6. Continue loading after the upper yield and watch carefully to obtain the extension and load at the lower yield point. In the plastic region record data for every 0.0100 in. of elongation. After the dial indicator reaches maximum travel, remove extensometer brackets and set dividers to next length. Continue to load and record data until the specimen fractures.
7. Inspect the fracture, fit the pieces together and measure the final elongation between punch marks. Measure width and thickness of the necked down section.

ANALYSIS GUIDE. Your report should include all the mechanical properties available from the tension test. Use the linear slope of the stress-strain diagram to find the modulus of elasticity. The area for the modulus of resilience can be found by breaking up the curved area into a series of smaller rectangles. How do your results compare with published data? Include a sketch of the fracture planes in your report. Did your specimen show a cup-cone type of fracture? What does this mean? Include percent elongation of the two-inch gage length. What was the reduction in area of the necked down section.

Specimen	Width (in)	Thickness (in)	Area (in^2)
Soft Steel Initially			
Necked Down			

Elongation δ	Strain ϵ	Hyd. Press p	Hyd. Cyl. Area A_c	Load P	Specimen A	Stress s

Fig. 5-7 The Data Tables

PROBLEMS

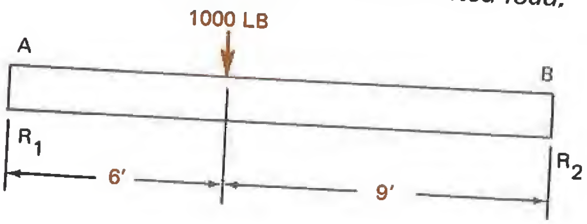
1. Calculate the hyper-elastic resilience for this specimen that would be obtained if point D on figure 5-2 were at the ultimate strength.
2. Instead of finding the area under the stress-strain curve to obtain modulus of toughness, an approximation is sometimes made by taking the product of the ultimate strength and corresponding elongation. This figure is called the Merit number. Calculate the merit number for your specimen. Note: The gage length must be reported when reporting merit number.
3. Plot the distribution of normal stress and shear stress in your specimen versus slant plane angle ϕ when the load is at the yield point. Find the shear force and the normal force when $\phi = 45°$. Do these two vectors add to the load P?
4. What is the maximum amount of mechanical energy per cubic inch that this material can absorb without plastic deformation?
5. What is the maximum amount of mechanical energy per cubic inch that this material can absorb before fracture?
6. Calculate a "true" fracture stress based on the necked down area of the specimen.

INTRODUCTION. The beam strength of a member depends on both the kind of material and the geometric cross section arrangement of the beam with respect to the load. The geometric aspects of beam strength will be explored in this experiment.

DISCUSSION. A beam is a structural or machine member that is subjected to loads acting in a transverse direction to its longitudinal axis, causing it to bend. The stresses that result are usually called bending stresses. Beams are classified according to their supporting structure. Several examples are shown in figure 6-1.

The first step toward solving beam problems involves finding all external forces acting on it. This must include the support reactions as well as the applied loads. Several examples of finding support reacting forces follow:

1. *Simple beam with a concentrated load.*



Support reactions are determined using the principle of moment equilibrium.

$$\Sigma M_A = 0$$

$$\Sigma M_A = (6)(1000) + (15)R_2 = 0$$

$$R_2 = \frac{6000}{15} = 400 \text{ lb}$$

$$\Sigma M_B = 0$$

$$\Sigma M_B = (9)(1000) - (15)R_1 = 0$$

$$R_1 = \frac{9000}{15} = 600 \text{ lb}$$

To check this we sum forces in the vertical direction.

$$\Sigma F_v = +600 - 1000 + 400 = 0$$

$$0 = 0 \text{ check}$$

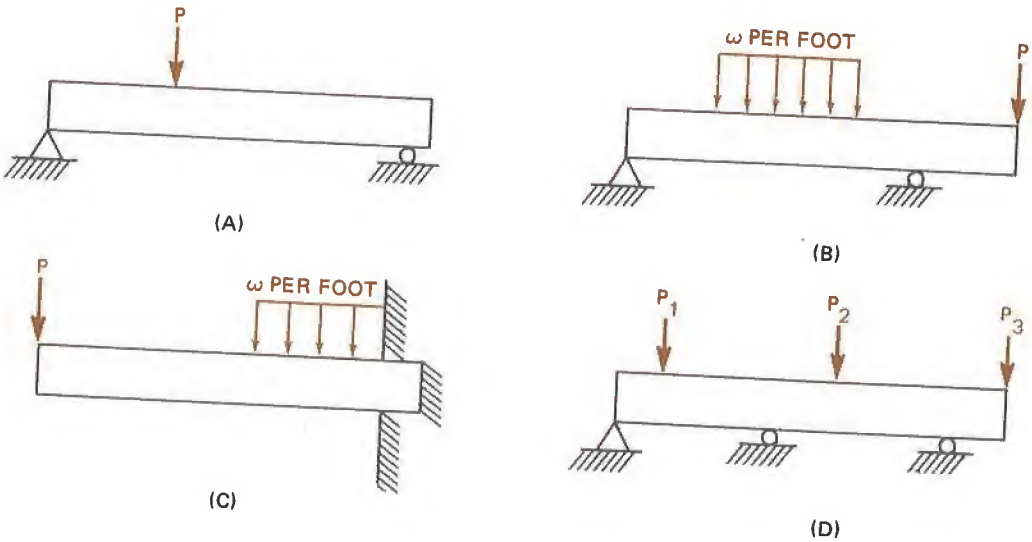
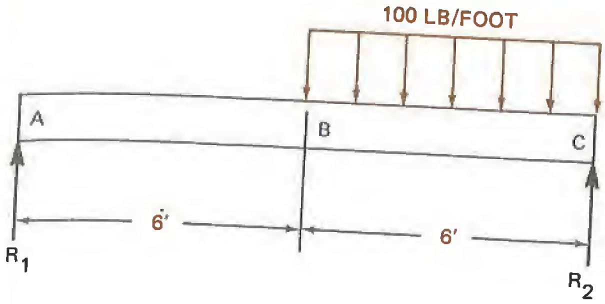


Fig. 6-1

2. Simple beam with distributed load.



The moment due to the distributed load is calculated by lumping the total force of the distributed load at its centroid. The total force is (100)(6) = 600 lb and the centroid is midway between B and C.

$$\Sigma M_A = -(600)(9) + 12\,R_2 = 0$$

$$R_2 = \frac{(600)(9)}{12} = \frac{5400}{12} = \mathbf{450\ lb}$$

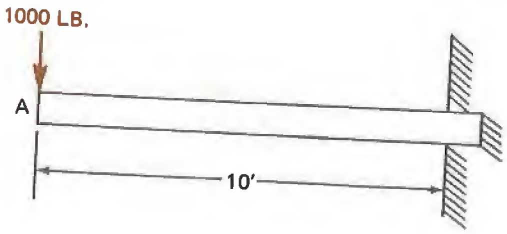
$$\Sigma M_{B_C} = (600)(3) - 12\,R_1 = 0$$

$$R_1 = \frac{1800}{12} = \mathbf{150\ lb}$$

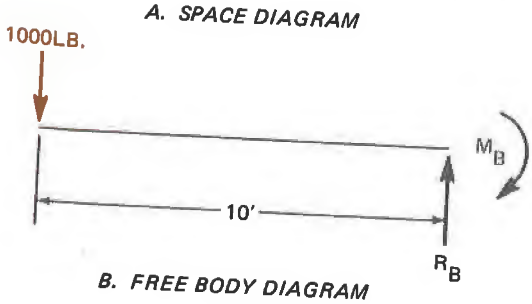
$$\Sigma F_V = 150 - 600 + 450 = 0$$

$$\mathbf{0 = 0\ \ Check}$$

3. Cantilever beam with concentrated load.



A. SPACE DIAGRAM



B. FREE BODY DIAGRAM

The cantilever beam cannot be held in equilibrium solely by the action reacting forces. Its true reacting force picture is actually quite complicated, but we establish equilibrium with a simplified picture using one opposing force and a moment as in example 3B. This is adequate for most situations. In example 3,

$$\Sigma F_V = 0$$

$$-1000 + R_B = 0$$

$$\mathbf{R_B = 1000\ lb}$$

$$\Sigma M_B = 0$$

$$(1000)(10) - M_B = 0$$

$$\mathbf{M_B = 10{,}000\ lb\ ft}$$

A beam in a state of equilibrium must be so at every section. The beam strength is limited by the maximum stress developed at the critical section. The kinds of stresses inside the beam are found by making an imaginary cut across the beam and investigating the free-body diagram. Figure 6-2 shows a simple beam and a simplified free-body diagram.

A cut section is made at an arbitrary spanwise location B and equilibrium requirements are established for the left portion. The same results are obtained by considering equilibrium of the right section, but it is conventional to consider the left. Requirements for equilibrium are:

1) $\Sigma F_V = 0 \Rightarrow \underline{V = R_1}$

2) $\Sigma M = 0 \Rightarrow \underline{M_X = R_1 X}$

The moment M_X is the internal resisting moment exerted by the righthand portion of the beam on the lefthand portion at section B. This moment must be transmitted through equal and opposite longitudinal forces within

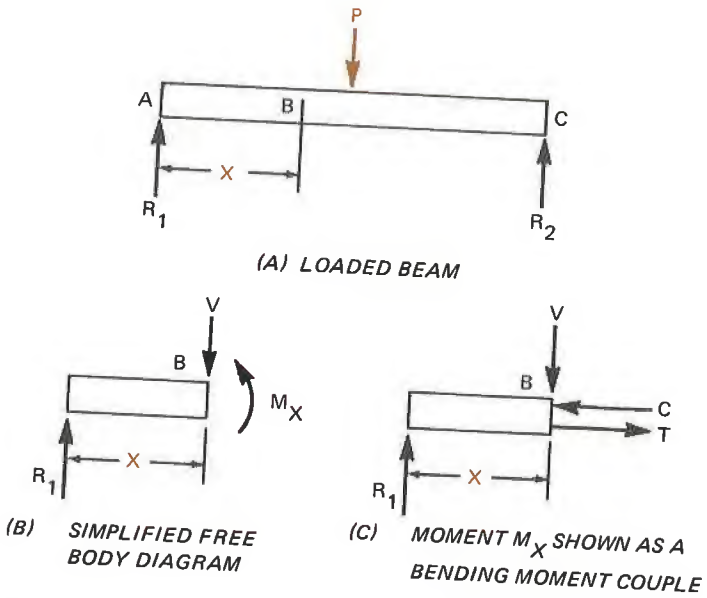


Fig. 6-2 Equilibrium Conditions for a Simple Beam

the beam. These forces constitute a bending moment couple as shown in figure 6-2(C). The longitudinal forces produced may be visualized by noting that action of load P will tend to make the beam bend to have a concave upper surface and a convex lower surface. This produces shortening of the upper fibers of the beam (compressive stress) and lengthening of the lower fibers (tensile stress). The next compressive force due to the compressive stresses is given by C in figure 6-2, and the net tensile force by T. **A beam is in equilibrium when the internal moment of the bending couple equals the external moment at that section and when the internal shear force V equals the external shear on either the right or left of that section.** In almost all beam problems the shear stress due to V is unimportant compared to the longitudinal stress caused by T and C. Stresses due to force T and C are called bending stresses and their distribution and magnitude will be found next.

The following table of observed phenomena in beams provides the guidelines for development of the beam formula.

OBSERVATION	CONCLUSION
1. Top fibers in the compression shorten by the same amount as the bottom fibers in tension	By Hooke's law the compressive stress in top fibers equals the tensile stress in bottom fibers.
2. Plane sections before bending remain plane after bending (figure 6-3).	Strain is linearly proportional to distance from the plane of zero deformation. Therefore, stress is linearly proportional to distance from the plane of zero deformation.
3. The plane dividing tensile and compressive strains has no longitudinal strain.	This plane must be without longitudinal stress — a neutral plane.

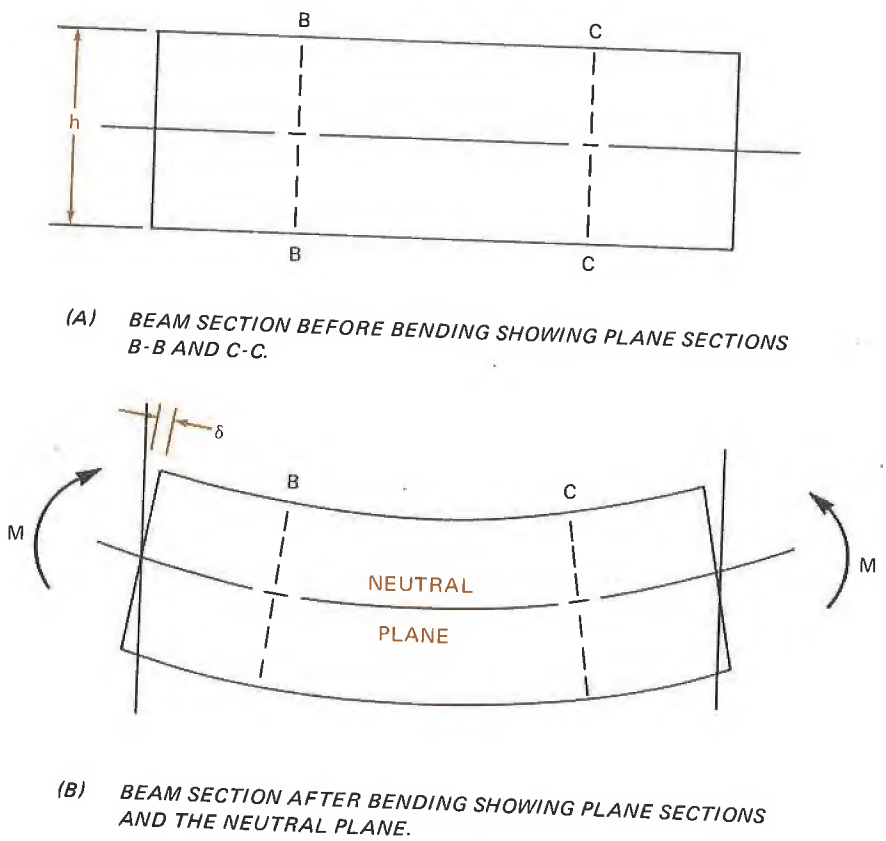


Fig. 6-3 Geometry Changes in Bent Beam Section

Based on the above observations and conclusions, the distribution and magnitude of the bending stresses may be found. Figure 6-4 shows the expected distribution of stress for a beam acted on by moment M.

The internal resisting moment is equal in magnitude to the applied moment M. The resisting moment is produced by summing up (integrating) the resisting moments of all the stresses acting on their respective areas. The elemental area dA has a force $(s_y)(dA)$ acting at distance y from the neutral axis, and so contributes resisting moment $(s_y)(y)(dA)$. Over the whole section these elemental re-

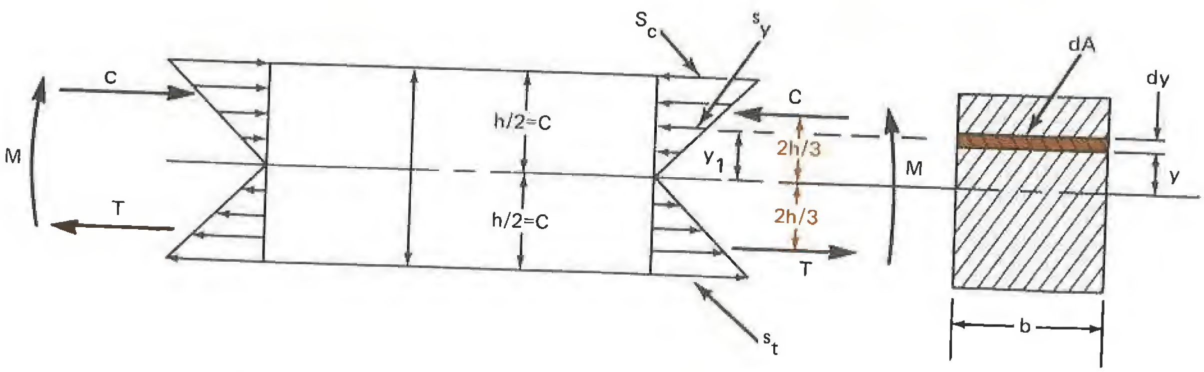


Fig. 6-4 Distribution of Tensile and Compressive Stresses

sisting moments are integrated as follows:

$$\boxed{M = \int_{-c}^{c} s_y y \, dA} \qquad (6.1)$$

where c is the distance from the neutral plane or axis to the extreme outer edge of the beam. The stress is always maximum on the beam surface. This stress is designated as s. The distribution of stress from the neutral axis to the outer surface is found by simple proportion.

$$\boxed{\frac{s_y}{s} = \frac{y}{c}} \qquad (6.2)$$

Using equation 6.2 in 6.1,

$$M = \int_{-c}^{c} \frac{sy}{c} y dA$$

$$\boxed{M = \frac{s}{c}\int_{-c}^{c} y^2 dA} \qquad (6.3)$$

Equation 6.3 is a fundamental result. The integral, $\int y^2 dA$, is a geometric property of the beam cross section. It is called the **moment of inertia** or **second moment** and is given the symbol I. Then,

$$M = \frac{sI}{c}$$

or

$$\boxed{s = \frac{Mc}{I}} \qquad (6.4)$$

where

s = bending stress (tensile or compressive) at a distance c from the neutral axis; psi

M = bending moment at the section; lb-in.

c = distance from neutral axis; inches

I = moment of inertia; in.^{4}.

Equation 6.4 is called the flexure formula. It is fundamental for design and analysis of beams. The form of equation 6.4 is used for analysis. For design it should be rearranged as

$$\boxed{\frac{I}{c} = \frac{M}{s_a}} \qquad (6.5)$$

Values for I are tabulated for all manufactured structural shapes. For others the inertia is readily found using $\int y^2 dA$.

The following examples illustrate the procedure for using these equations.

4. Find the maximum bending stress in the beam given in Fig. 6-5.

The use of equation 6.4 means we have to find the moment at some appropriate section and the moment of inertia, I. Clearly, the maximum stress will occur at the section of maximum moment. The best method of insuring that the proper value of moment is being used is to sketch a moment diagram. This is shown in Fig. 6-5. The sign convention used is that moments causing compression on the top of the beam and tension below are considered positive. The values can be found by taking a free body at any section and calculating the moment there. At any section between A and the load the moment is R_1X. Between the load and end B the moment is $R_1X - 1000(6-X)$. Calculation of several values result in the moment diagram shown. The maximum moment occurs under the load making this the critical section.

The moment of inertia for any rectangular section b units wide and h units high is

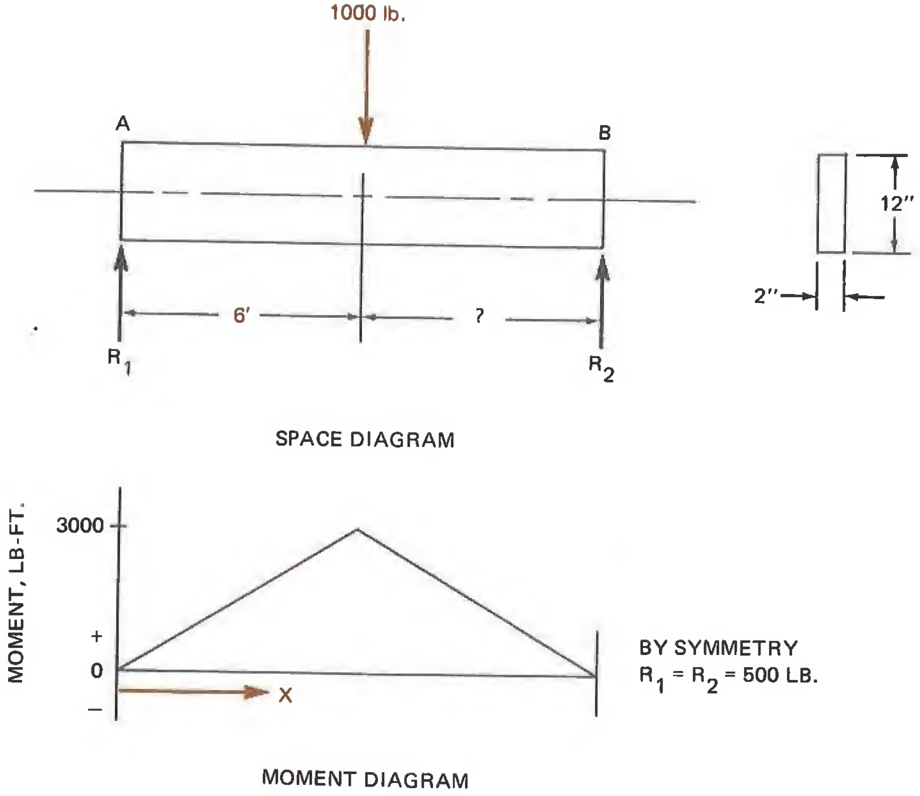
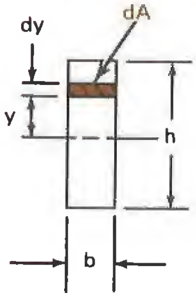


Fig. 6-5

found as follows:



$$I = \int y^2\, dA$$

$$= \int_{-h/2}^{h/2} y^2 dA = \int_{-h/2}^{h/2} y^2\, b dy$$

$$= 2b \int_{o}^{h/2} y^2 dy = 2b \left.\frac{y^3}{3}\right|_{o}^{h/2}$$

$$I = \frac{2b}{3}\frac{h^3}{8} = \frac{bh^3}{12}$$

For the 2" X 12" section, Fig. 6-5,

$$I = \frac{2 \times 12^3}{12} = \frac{2}{12}\ 1728 = \mathbf{288\ in.^4}$$

The maximum bending stress is

$$s = \frac{Mc}{I} = \frac{(3000)(12)(6)}{288} = \mathbf{750\ psi}$$

Note that the moment must be expressed in inch-lb (3000)(12).

The orientation of the beam with respect to the load is most important for obtaining maximum strength. This is seen in the I and c values. Suppose this beam were used in a flatwise orientation. The dimensions b and h would change roles and I would be much smaller resulting in a large stress. Often equation 6.4 is written as

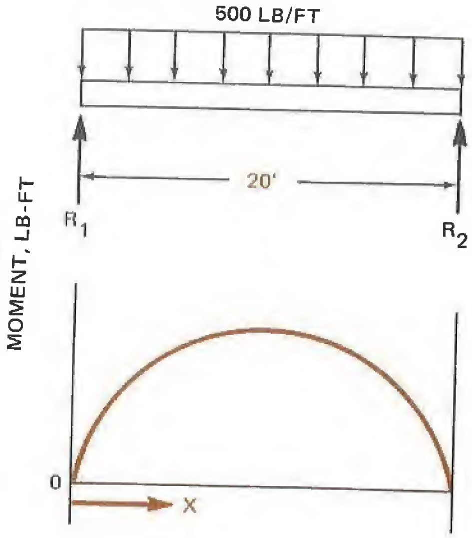
$$\boxed{s = \frac{M}{Z}}$$

where

$$Z = \frac{I}{c} = \text{section modulus, in.}^3$$

For a rectangular section

$$Z = \frac{\frac{bh^3}{12}}{\frac{h}{2}} = \frac{bh^2}{6}.$$



TOTAL LOAD
= (500) (20) = 10,000 LB.
BY SYMMETRY
$R_1 = R_2 = 5000$ LB.

Fig. 6-6

In the example above,

$$Z = \frac{bh^2}{6} = \frac{2(12)^2}{6} = \frac{144}{3} = \mathbf{48\ in.^3}$$

If the beam were used flatwise, the section modulus would be

$$Z_{flat} = \frac{bh^2}{6} = \frac{12(2)^2}{6} = \frac{48}{6} = \mathbf{8\ in.^3}$$

or

$$\frac{Z}{Z_{flat}} = \frac{48}{8} = \mathbf{6.}$$

The beam is 6 times stronger on edge than in the flatwise position. Both the I values and A values are tabulated for standard structural sections. For any given loading situation, one can select the strongest beam simply by glancing at tabulated values of section modulus, Z.

5. A steel beam is loaded as shown in Fig. 6-6. The allowable design stress is 20,000 psi. Find the section modulus necessary to limit the bending stress to 20,000 psi.

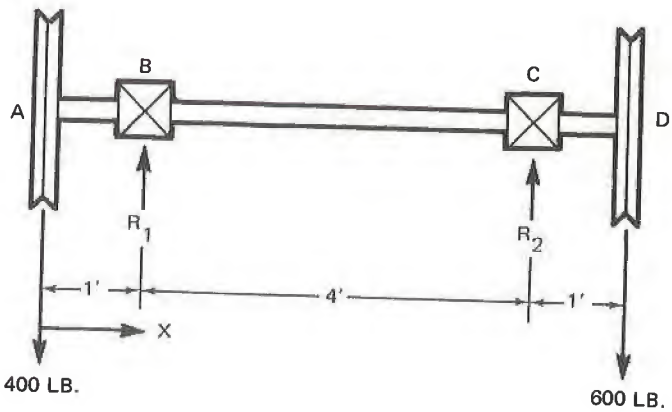


Fig. 6-7

The moment at any section is

$$R_1X - \frac{\omega X^2}{2}$$

where $\omega X(X/2)$ is the moment due to the distributed load. The resulting moment diagram is the parabola shown. The maximum moment is

$$(5000)(10) - \frac{(500)(10)^2}{2} = 50{,}000 - 25{,}000$$

$$= 25{,}000 \text{ lb-ft},$$

or 300,000 lb-in.

$$Z = \frac{M}{s_a}$$

$$Z = \frac{300{,}000}{20{,}000} = 15 \text{ in.}^4$$

6. The net belt tension forces exerted on the pulleys of the overhanging shaft are 400 lb and 600 lb as shown in Fig. 6-7. Find the maximum bending stress in the solid shaft if it is 1.5" O.D. Let us use a step-by-step procedure which can be used for most beam problems.

Step 1. Find the bearing reacting forces.

$$\Sigma M_B = (400)(1) + R_2(4) - 600(5) = 0$$

$$R_2 = \frac{3000 - 400}{4} = \frac{2600}{4} = 650 \text{ lb}$$

$$\Sigma M_c = -600(1) - R_1(4) + 400(5) = 0$$

$$R_1 = \frac{2000 - 600}{4} = \frac{1400}{4} = 350 \text{ lb}$$

$$\text{Check: } \Sigma F_V = -400 + 350 + 650 - 600$$

$$= 1000 - 1000$$

$$= 0$$

Step 2. Plot the moment diagram. Between sections A and B

$$M = -400X, \quad 0 < X < 1$$

Moment is negative since the top of the shaft is in tension.

Between sections B and C

$$M = 400X + R_1(X - 1) = 400X + 350(X - 1),$$

$$1 < X < 5$$

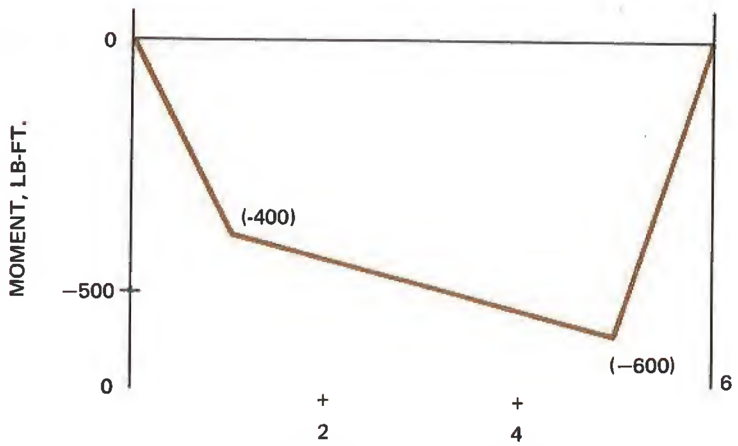
Between sections C and D

$$M = -400X + R_1(X - 1) + R_2(X - 5)$$

$$= -400X + 350(X - 1) + 650(X - 5),$$

$$5 < X < 6$$

The graph of these three moment equations is shown below.



The critical section is at the right bearing support where the moment is –600 lb-ft.

Step 3. The flexure formula, equation 6.4, is now applied.

$$s = \frac{Mc}{I}$$

For the 1.5-inch diameter shaft,

$$c = \frac{D}{2} = 0.75 \text{ in.}$$

and

$$I = \frac{\pi D^4}{64} = \frac{\pi(1.5)^4}{64} = 0.248 \text{ in.}^4$$

Then

$$s = \frac{(600)(12)(.75)}{(.248)} = 21{,}750 \text{ psi}$$

Note that the negative sign for moment makes no difference in the stress calculations. It simply means that the top of the shaft is in tension and the bottom is in compression.

MATERIALS

1 Loading frame with 2-1/2 in. diameter hydraulic load cylinder
2 1/2 in. X 1 in. X 18 in. HR steel beams
3 Dial indicator and magnetic base
2 Specimen connectors
1 Load connector

PROCEDURE

1. Inspect the apparatus for proper working order. The dial indicator should have free movement. Both beams should have 1/4 in. mounting holes 18 in. apart.
2. Mount one beam in the loading frame in a flatwise position using specimen connectors. Center the loading cylinder above the beam so you will have a simply supported beam with a concentrated load at the center.
3. Mount the extensometer on the frame base and set the plunger on the beam near the load with all slack removed from the linkages. Zero the extensometer.
4. Load the beam in increments of 50 lb and record load and deflection. Continue loading until the beam has obviously failed. Be careful not to damage the extensometer due to overload.
5. Repeat steps 2, 3, and 4 with the second beam in the upright position.

ANALYSIS GUIDE. You should plot a load-deflection diagram to help determine the load at which the beams fail. Both beams were made of the same material and had the same area in cross section. Why is one stronger than the other? Did they fail at the same stress level? Can you correlate the ratio of load at failure to any geometric property? Which one?

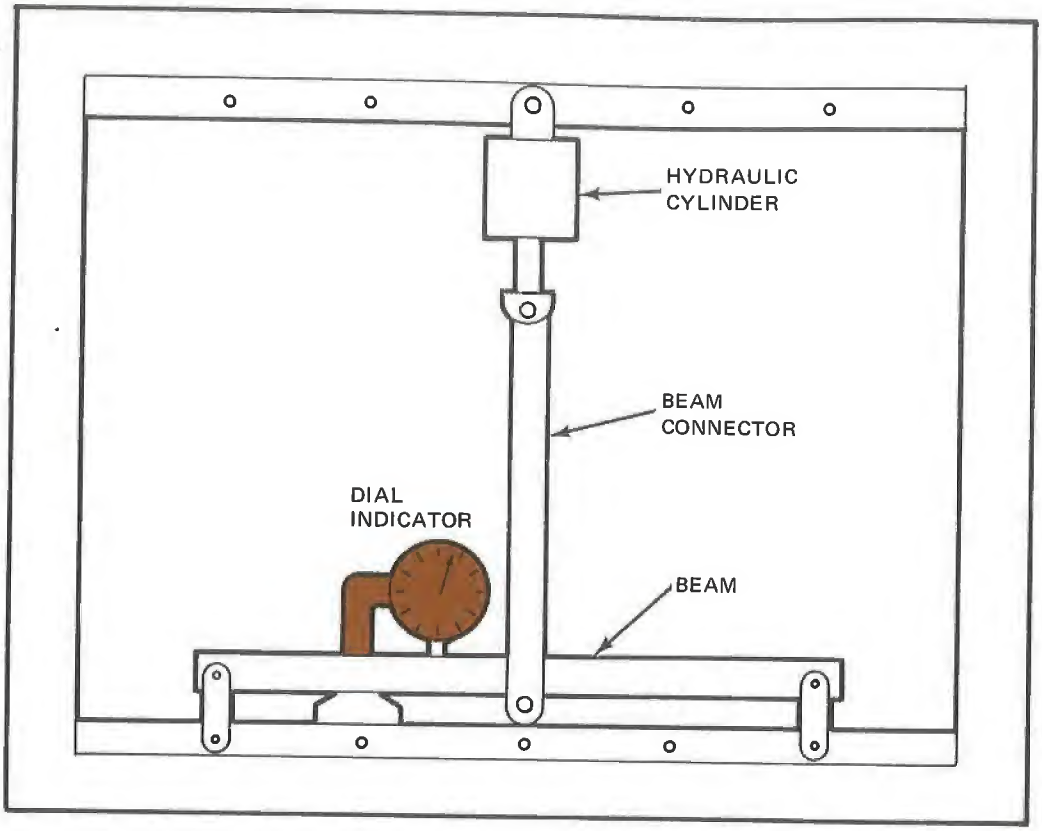


Fig. 6-8 The Experimental Setup

Beam Flatwise

Hyd Press p	Hyd Cyl Area, A_c	Load P	Beam Deflections

Fig. 6-9 The Data Tables

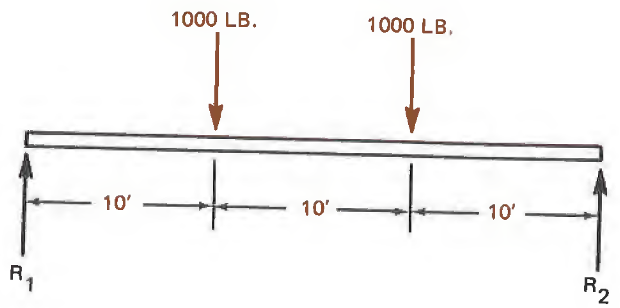
Beam Upright

Hyd Press p	Hyd Cyl Area, A_c	Load P	Beam Deflections

Fig. 6-9 The Data Tables (Cont'd)

PROBLEMS

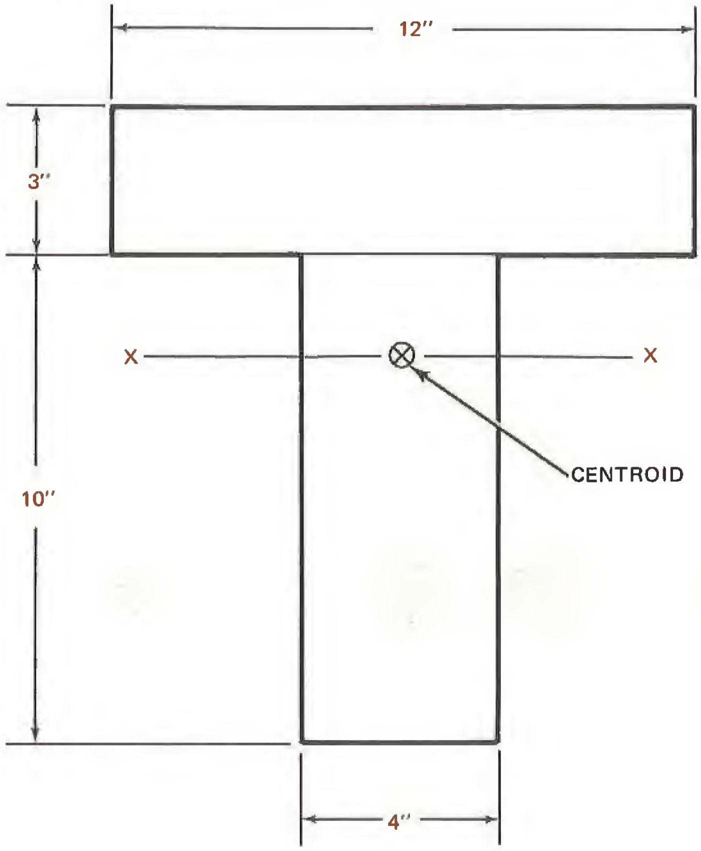
1. Draw the bending moment diagram for the beam loaded as shown. Where is the critical section for bending?



2. A 2 X 12 plank has an actual size of 1-1/2 X 11-1/2 in. A 2 X 8 plank has an actual size of 1-1/2 X 7-1/2 in. When used as joists (beams), calculate how many 2 X 8s must be used to be at least as strong as one 2 X 12.

3. American standard I beams 5 in. X 3 in. are built in heavy and light weights. The heavy beam has $I = 15.0$ in.^{4} and $Z = 6.0$ in.^{3}. The light beam has $I = 12.1$ in.^{4} and $Z = 4.8$ in.^{3}. Disregarding the beam weight, determine what percent greater load the heavy beam will carry under the same loading conditions.

4. Find the centroid (neutral axis) and 2nd moment for the T beam section made up of two rectangles as shown. Use the transfer equation for the second moment $I_X = \Sigma(I_c + Ad^2)$.



experiment **7** *STRENGTH OF CONNECTORS AND JOINTS*

INTRODUCTION. A large number of mechanical devices are fastened using pins, rivets, and bolts. In this experiment the strength of these connections will be investigated.

DISCUSSION. Moving links, cranks, roller chains, frames, beams and girders, and pressure vessels are examples of mechanical fasteners using pins, rivets, or bolts. These fasteners all must carry shear loads and, in turn, they produce compressive (bearing), tensile, and tearing forces on the joint. Figure 7-1 shows a joint and the various forces and possible failure modes due to these forces.

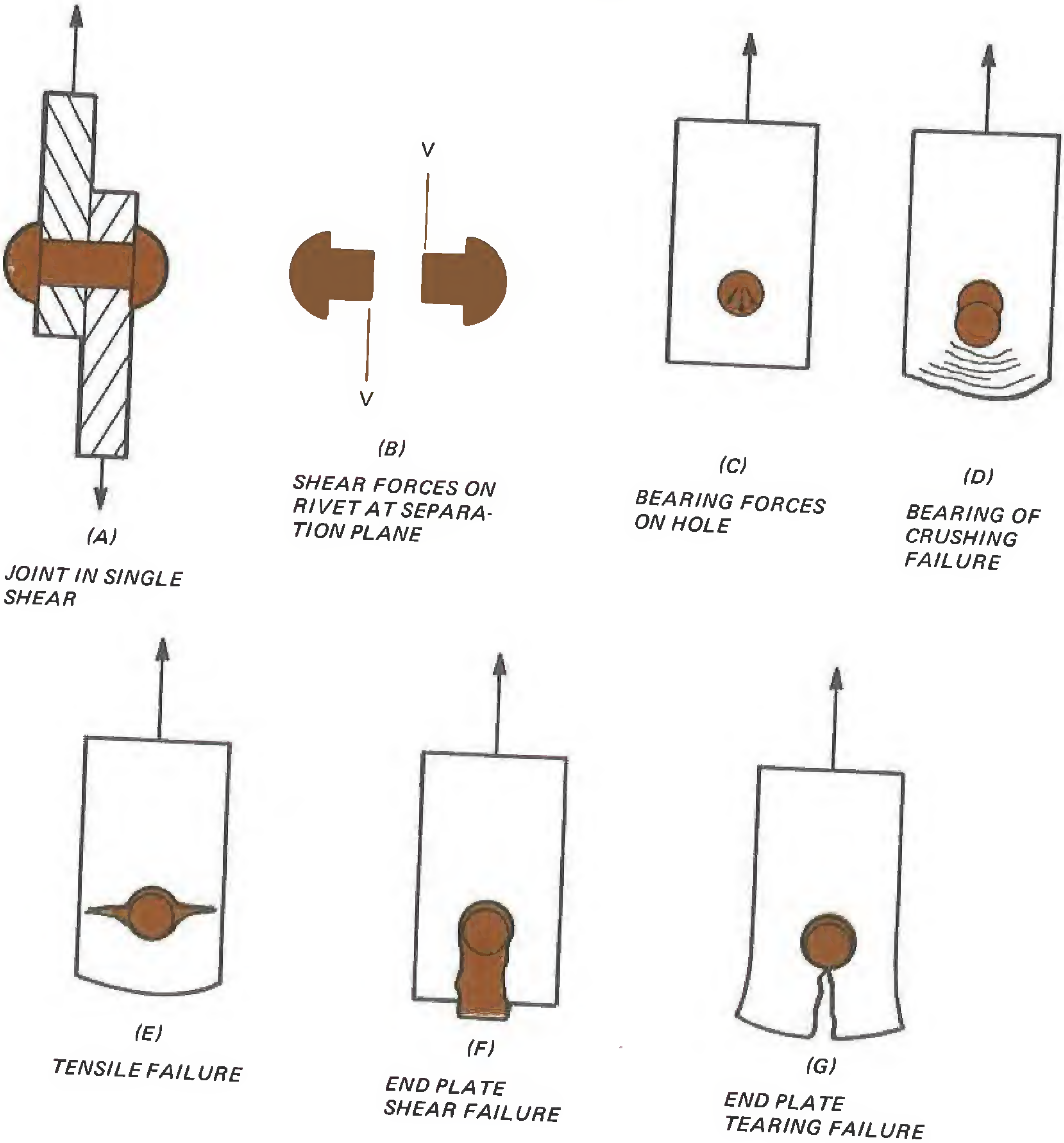


Fig. 7-1 Forces and Failure Modes of a Riveted Joint

The strength of a connection depends on which mode of failure offers the least resistance to the applied load. Often a failure will occur in two or more modes simultaneously. In practice one must calculate the load-carrying ability of the joint considering different failure possibilities. **The calculation which shows the least strength is the strength of the joint.**

The design load for structural connections is calculated from an allowable stress times the stressed area.

$$\boxed{P_{DES} = sA} \qquad (7.1)$$

where

P_{DES} = design load

s = safe allowable stress

A = corresponding stressed area.

Values for structural connections are recommended by the American Institute of Steel Construction (AISC). These values carry a safety factor by specifying an allowable stress below the actual yield stress.

If you wish to calculate the failure load, the yield stress value should be used. Yield stress and allowable or design stress are related by

$$\boxed{s = \frac{s_y}{n}} \qquad (7.2)$$

where

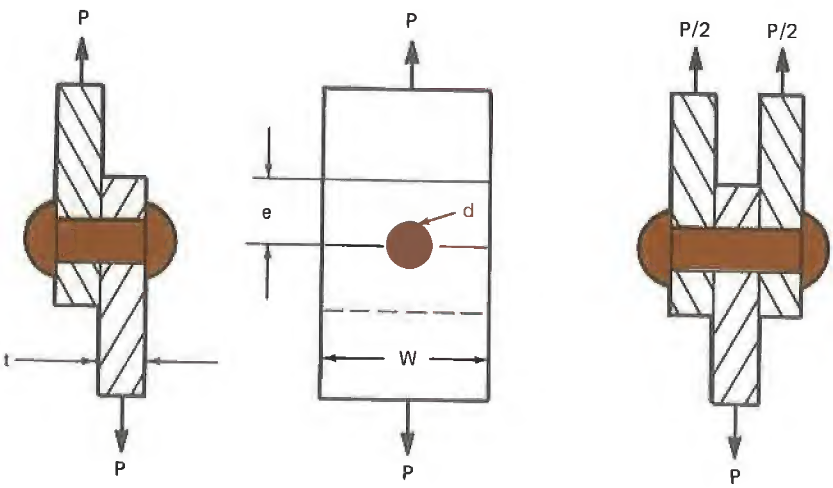
s = design (allowable) stress

s_y = material yield stress from the tension test

n = safety factor

In structures and machines used by humans, minimum safety factors are usually specified by law. Where human life is not involved, the consequences and economics of failure enter into the choice of n. A safety factor that is too small may result in excessive failures while overly generous values of n result in excessive weight, cost, and inability to compete in a free market.

Appropriate values for the stressed area are found as follows:



(A) *SINGLE SHEAR*

(B) *FRONT VIEW OF SINGLE SHEAR*

(C) *DOUBLE SHEAR*

Fig. 7-2 Riveted Joints

1. Shearing stress. The unit shearing stress is:

$$\boxed{s_s = \frac{P}{A_s}} \qquad (7.3)$$

where

$$A_s = \frac{\pi D^2}{4}$$

for single shear, as in figure 7-2(A), and

$$A_s = (2)\frac{\pi D^2}{4} = \frac{\pi D^2}{2}$$

for double shear, as in figure 7-2(B).

2. Bearing stress. The area carrying the bearing load is semi-cylindrical and is generally larger in diameter than the pin or rivet. The distribution of stress is complex. It is customary to make a nominal (approximate) stress calculation using the area given by the pin diameter and the plate thickness. This unit stress, while not a true value, can be used for design calculations since allowable values have been determined by tests of joints. Then

$$\boxed{s_B = \frac{P}{A_B}} \qquad (7.4)$$

where

$$A_B = Dt$$

and

D = Rivet, bolt, or pin diameter

t = minimum plate thickness

3. Tensile stress. The minimum area carrying tensile load normally cuts through the center of the hole. Again, the stress pattern is complicated by the hole, but a nominal figure is satisfactory when ductile materials are used.

$$\boxed{s_t = \frac{P}{A_t}} \qquad (7.5)$$

where

$$A_t = (w - D)\ (t)$$

In large structural joints, rivet holes are generally punched to an oversize for ease of assembly. To compensate for oversize and wall damage due to punching, the hole diameter is taken as 1/8 larger than rivet diameter. Then

$$A_t = [w - (D + 1/8)]\ t.$$

4. End tearing. The end plate failures as shown in figure 7-1(F) and (G) usually occur as combinations of crushing and shearing or crushing and tearing. This failure can be avoided by making distance e shown in figure 7-2(B) sufficiently large. In practice,

$$\boxed{e > \frac{A_s}{t}} \qquad (7.6)$$

will usually prevent the end failure.

The following examples will illustrate the use of these equations.

Find the shearing stress, bearing stress, and tensile stress for the bolted connection shown in figure 7-3. Is there any danger of end tearing?

Shear. For single shear:

$$s_s = \frac{P}{A_s} = \frac{P}{\frac{\pi D^2}{4}} = \frac{7500}{0.785} = \mathbf{9560\ psi}$$

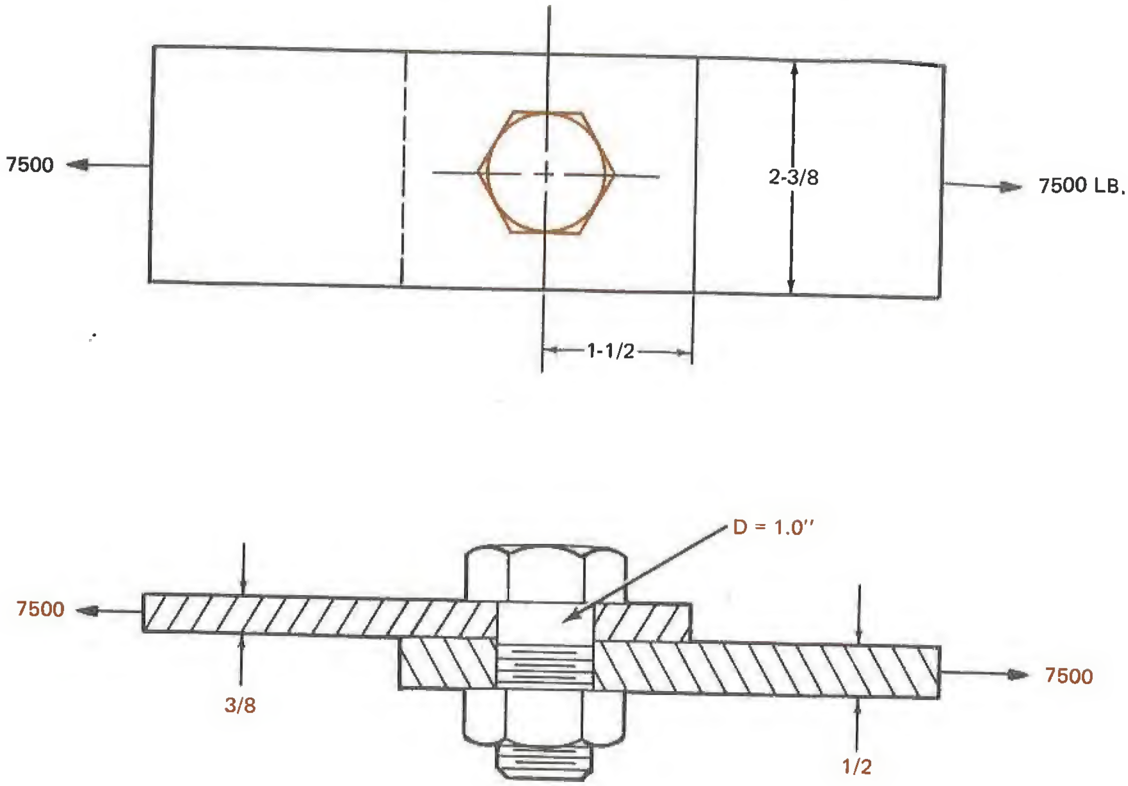


Fig. 7-3 A Bolted Connection

Bearing. The thinnest plate will obviously have the greatest bearing stress.

$$s_B = \frac{P}{A_B} = \frac{P}{Dt} = \frac{7500}{(1)\,(3/8)} = \mathbf{20{,}000\ psi}$$

Tensile. Again the thinnest plate will incur the largest stress. For an unfinished bolt, we will assume a hole diameter 1/8 larger than the bolt.

$$s_t = \frac{P}{A_t} = \frac{P}{[w - (D + 1/8)]\ t}$$

$$= \frac{7500}{[2.375 - (1.125)]\ (.375)}$$

$$s_t = \frac{7500}{(1.25)\,(.375)} = \mathbf{16{,}000\ psi}$$

End tearing.

e = 1-1/2 in. (given)

$$\frac{A_s}{t} = \frac{(.785)}{(.375)} = 2.09$$

Therefore,

$$\boxed{e < \frac{A_s}{t}}$$

and there is a danger of end tearing.

No allowances have been made for a tightly-bolted connection in which friction between plates plays a major role in carrying the connection load. The bolt in this case may have a reduced shear load but must carry a high tensile load. The end result of these combined stresses is to reduce the allowable shear stress for the friction connection.

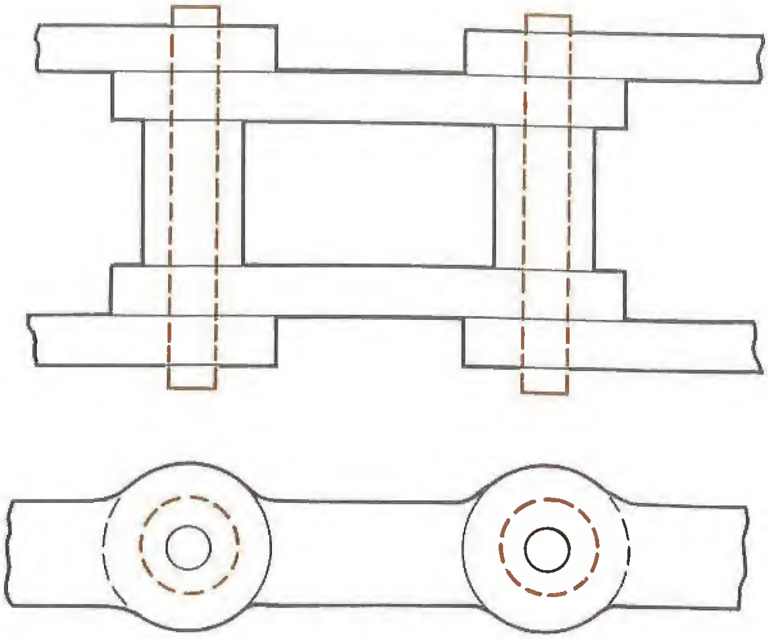


Fig. 7-4 A Roller Chain Link

A section of roller chain is shown in figure 7-4. The connecting links are 3/8 in. thick by 1-1/2 in. wide between pins and 2-1/4 in. wide across the pins. The pins are finished and are 1/2 in. diameter and close fitting. The roller bushings will not enter into the calculations. Find the shear, bearing, and tensile stresses for a load of 3000 lbs.

Shear. The shear load is carried at two points so area for double shear is used.

$$s_s = \frac{P}{A_s} = \frac{P}{\frac{\pi D^2}{2}} = \frac{3000}{\frac{\pi(1/2)^2}{2}} = \frac{24{,}000}{\pi} = \mathbf{7650\ psi}$$

Bearing.

$$s_B = \frac{P}{A_B} = \frac{P}{2Dt} = \frac{3{,}000}{2(1/2)\ (3/8)} = \mathbf{8{,}000\ psi}$$

Tensile.

$$s_t = \frac{P}{A_t} = \frac{P}{2\omega t} = \frac{3{,}000}{2(1.5)\ 3/8} = \mathbf{2665\ psi}$$

The bell crank shown in figure 7-5 has a force H = 2400 lbs. If a = 4 in. and b = 3 in., find the shearing stress in pin A if it is 1/2 in. diameter.

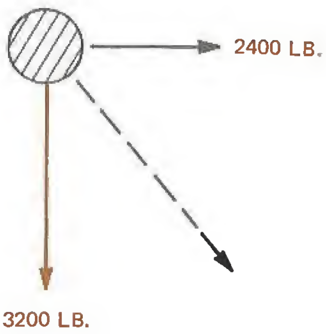
The pin load must be found first. For equilibrium,

$$\Sigma M_A = 0$$

$$\Sigma M_A = Ha - Tb = 0$$

$$T = \frac{Ha}{b} = \frac{(2400)\ (4)}{3} = \mathbf{3200\ lbs.}$$

The pin load is the resultant of H and T.



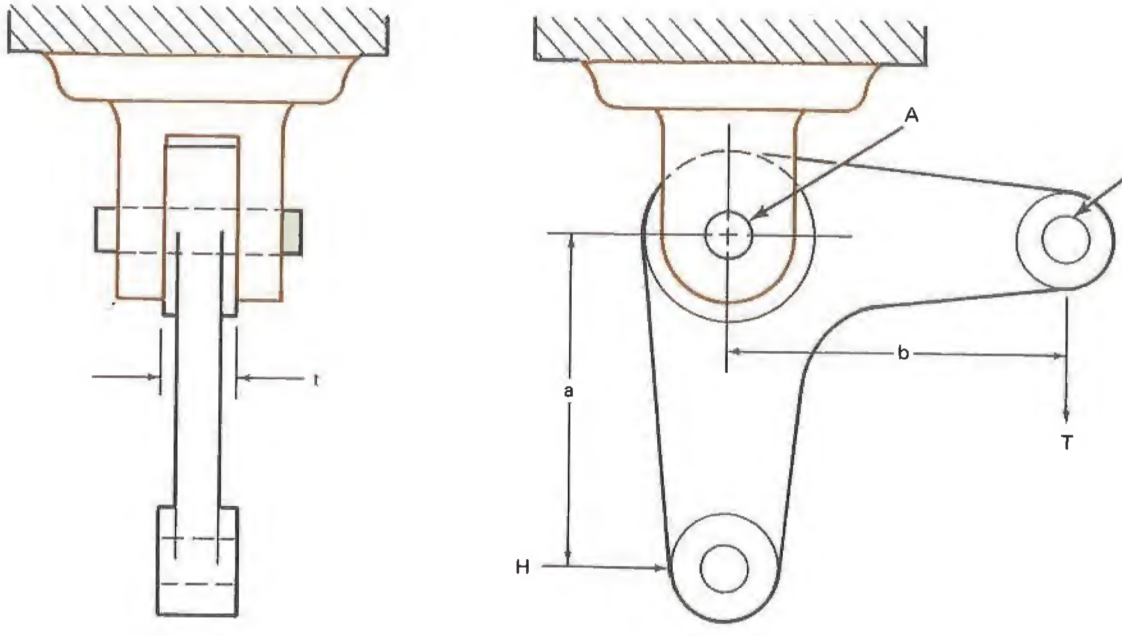


Fig. 7-5 A Bell Crank

Using the Pythagorem theorem,

$$P = \sqrt{(2400)^2 + (3200)^2}$$

$$= \sqrt{(576 + 1024)10^4}$$

$$P = 100\sqrt{1600} = \mathbf{4000\ lbs.}$$

The pin is in double shear.

$$s_s = \frac{P}{A_s} = \frac{4{,}000}{\frac{\pi(1/2)^2}{2}} = \frac{32{,}000}{\pi} = \mathbf{10{,}200\ psi}$$

Find the yield strength of the bolted joint shown in figure 7-6. The bolts are 3/16 in. diameter fitted in close tolerance holes. All plates are 1/2 in. in width. The tensile yield strength of the steel plates and bolts is 40,000 psi.

Since the joint could fail by bolt shear, bearing failure, or tensile failure, the strength must be calculated in these three modes, and the least strength will be the strength of the joint.

Shear. Each pair of bolts carries the load

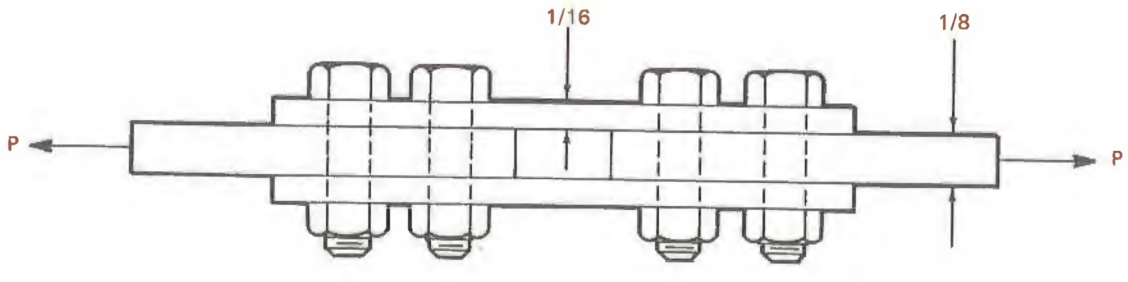


Fig. 7-6 A Bolted Joint Using Splice Plates

P in the double shear. The yield strength in shear is

$$\boxed{P_s = s_{s_y} A_s} \qquad (7.7)$$

where s_{s_y} is the shear yield strength the shear yield is one half the tensile yield.

$$s_{s_y} = \frac{s_y}{2} = \frac{40{,}000}{2} = 20{,}000 \text{ psi}$$

$$A_s = (2)\,\frac{\pi D^2}{2} = \pi D^2 = \pi\left(\frac{3}{16}\right)^2 = \frac{9\pi}{256}\text{ in.}^2$$

$$P_s = (20{,}000)\,\frac{9\pi}{256} = \mathbf{2210\ lbs.}$$

Bearing. The bearing yield strength can be taken as the tensile yield.

$$\boxed{P_B = s_B A_B} \qquad (7.8)$$

The bearing area includes two bolts and minimum bearing plate thickness. The outside plates together add to 1/8 in. of plate for outside bearing area. The inside plate is also 1/8 in. thick so the inside and outside bearing calculations will be identical.

$$P_B = (40{,}000)\ (2)\left(\frac{3}{16}\right)\left(\frac{1}{8}\right) = \mathbf{1875\ lbs.}$$

Tensile. Minimum tensile area occurs across the inner bolts.

$$\boxed{P_t = s_t A_t} \qquad (7.9)$$

$$P_t = (40{,}000)\ (1/2 - 3/16)\ (1/8)$$

$$= 40{,}000\left(\frac{5}{16}\right)\left(\frac{1}{8}\right)$$

$$P_t = \mathbf{1563\ lbs.}$$

The strength of this joint is around 1563 pounds and failure will occur in tension across the inner bolts.

MATERIALS

- 1 Loading frame with 2-1/2 in. diameter hydraulic load cylinder
- 1 Specimen connector
- 1 Type A joint
- 1 Type B joint

PROCEDURE

1. Inspect both joints. Carefully measure each important dimension and record.
2. Predict the ultimate strength of each joint and the mode of failure for each joint.
3. Mount the type A joint and load the joint to destruction.
4. Repeat step 2 for the type B joint.

ANALYSIS GUIDE. Does using ultimate shear strength equal to one-half the yield give reasonable results? Calculate a percent error between predicted and actual joint strength for each joint. Considering the complex stress distribution, are these results adequate?

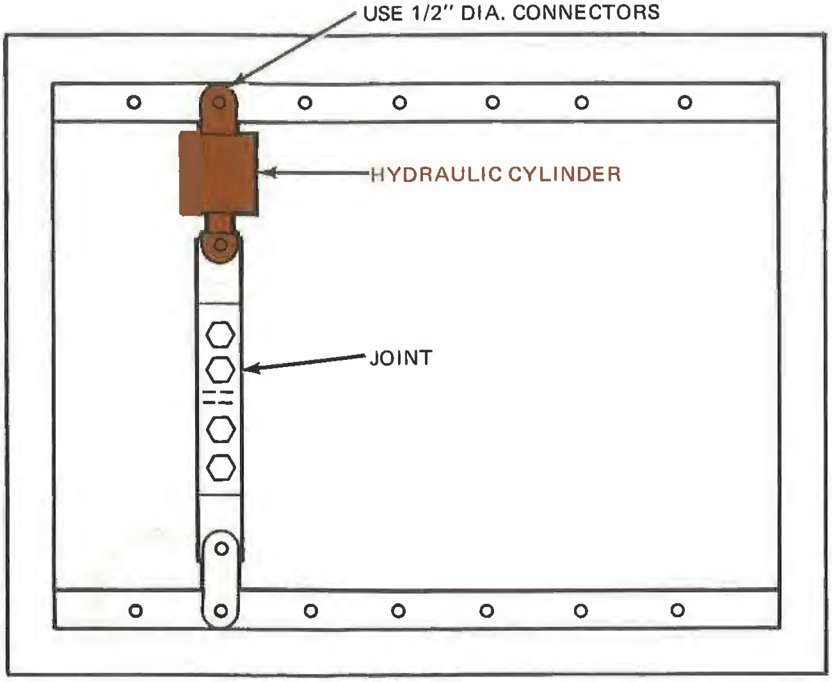


Fig. 7-7 The Experimental Setup

Type A Joint, Rivet Dia =

Outer Plate t =

Inner Plate t =

Width =

e =

Material; s_u = $s_{su} = su/2 =$

Type B Joint, Rivet Dia =

Plate t =

e =

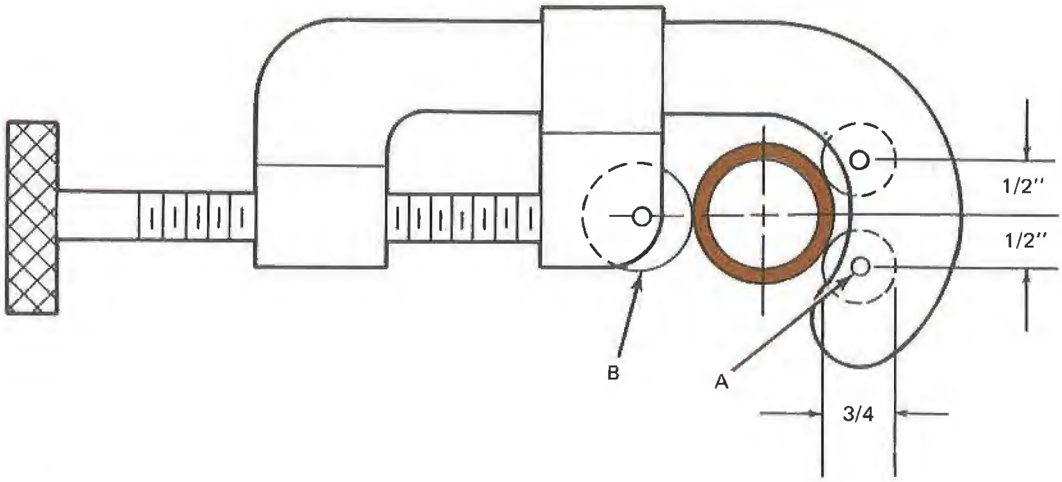
Material s_u = $s_{su} = \frac{su}{2} =$

Joint Type	Hyd Press p	Hyd Cyl Area, A_c	Actual Load P at Failure	Predicted Load at Failure
A				
B				

Fig. 7-8 The Data Table

PROBLEMS

1. For the type A joint, calculate a safety factor based on the experimental ultimate strength if the allowable shear stress were given as 15,000 psi, i.e., $m = s_u/s_{allow}$.
2. Estimate the ultimate strength of joint B if w were 1.0 inch.
3. The tubing cutter shown is used to cut 1-1/4 in. OD pipe. If the axle of wheel A is 1/4 in. in diameter and supported at both ends, calculate the shearing stress in the axle if wheel B is exerting a force of 500 lbs on the pipe.



experiment 8 HARDNESS TESTING

INTRODUCTION. Hardness testing is one of the most common methods of testing materials. This is because hardness of a material is directly related to tensile strength and ductility of that material.

DISCUSSION. Hardness is defined as the resistance to indentation of one material on another. We use this definition of hardness every day. When we eat we are checking the resistance to indentation of our food with our teeth. The doughnut you had with your coffee this morning was either fresh, soft, or stale, hard. Therefore, to perform a hardness test we must have some type of penetrator and some load on this penetrator.

Standard types of hardness tests have been established with standard loads and penetrators. Two of these **standard tests** are the **Brinell** and **Rockwell.**

For the purpose of this experiment we will only be discussing the Rockwell hardness test. Table one gives the approximate hardness vs tensile strength of steel. The Rockwell hardness tester has numerous scales that can be used. These scales are used for either hard, medium hard, and soft materials. The **Rockwell C** scale is used for hardened steel or other very hard materials. If in doubt about the hardness of a material, always use the C scale first. This is to prevent damage to the steel ball. The **Rockwell B** scale is used for softer materials such as brass, aluminum, soft steel, and the like.

Both scales of the Rockwell work on the same principle: that is, loading a penetrator until it plastically deforms a material and then measuring the depth of indentation. The amount of plastic deformation usually does not affect the material in service.

To get a feeling of hardness numbers the following chart was made.

A. *Below B-50; very soft, easily bent.*
B. *B-70; Medium strength, tough to bend.*
C. *B-90; approximately C-10, high strength, tough.*
D. *Under C-30; can be machined, higher strength.*
E. *Over C-30; cannot be machined or cut by conventional methods, very strong, becoming brittle.*
F. *C-64; maximum hardness, very strong, brittle.*

A correlation does exist between a hardness test and tensile strength of a material.

Type	Load	Penetrator
Brinell	3000 kgm	10mm steel ball
Brinell	500 kgm	10mm steel ball
Rockwell B	100 kgm	1/16 steel ball
Rockwell C	150 kgm	Conical Diamond

If a tensile test and a hardness test is taken on a material, we can determine the tensile strength of that material by a hardness test only. Therefore, hardness testing is very useful in quality control of parts being fabricated.

Approximate Correlation Between Hardness and Tensile Strength

Rockwell[1]		Tensile strength 1,000 PSI	Rockwell[1]		Tensile strength 1,000 PSI	Rockwell[1]		Tensile strength 1,000 PSI	Rockwell[1]		Tensile strength 1,000 PSI
C, 150-kg. load	B, 100-kg. load 1/16 in. ball		C, 150-kg. load	B, 100-kg. load 1/16 in. ball		C, 150-kg. load	B, 100-kg. load 1/16 in. ball		C, 150-kg. load	B, 100-kg. load 1/16 in. ball	
67		350	44	114.4	208	21	99.5	110		83.2	76
66		345	43	113.8	201	20	98.9	107		82	74
65		340	42	113.3	194	19	98.1	104		80.5	72
64		335	41	112.7	188	18	97.5	103		79	70
63		330	40	112.1	181	17	96.9	102		77.5	68
62		325	39	111.5	176	16	96.2	100		76	66
61		320	38	110.9	170	15	95.5	99		74	64
60		315	37	110.4	165	14	94.9	97		72	62
59		310	36	109.7	160	13	94.1	95		70	60
58		305	35	109.1	155	12	93.4	93		68	58
57		300	34	108.5	150	11	92.6	91		66	56
56	121.3	295	33	107.8	147	10	91.8	90		64	54
55	120.8	288	32	107.1	142	9	91.2	89		61	52
54	120.2	286	31	106.4	139	8	90.3	88		58	50
53	119.6	283	30	105.7	136	7	89.7	87		55	48
52	119.1	273	29	105.0	132	6	89	85		51	46
51	118.5	264	28	104.3	129	5	83.3	84		47	44
50	117.9	256	27	103.7	126	4	87.5	83		44	42
49	117.4	246	26	102.9	123	3	87	82		39	40
48	116.8	237	25	102.2	120	2	86	81		35	38
47	116.2	231	24	101.5	118	1	85.5	80	30		36
46	115.6	221	23	100.8	115	0	84.5	78	24		34
45	115.0	215	22	110.2	112				20		32
									11		30
									0		28

Fig. 8-1 Table 1

MATERIALS

1 Rockwell hardness tester set up for both the R-B and R-C scales
1 Piece of yellow brass 1/2 in. diameter X 1 in. long
1 Piece of 2024-T6 aluminum, 1/2 in. diameter X 1 in. long
1 Piece of 1018 steel, 1/2 in. diameter X 1 in. long
1 Piece of 304 stainless, 1/2 in. diameter X 1 in. long
1 Piece of drill rod 1/2 in. diameter X 1 in. long
1 Piece of tool steel, 1/2 in. diameter X 1 in. long
1 File with cutting teeth ground off
2 Unknown materials to determine hardness
1 Welding rods of yellow brass, 1/8 in. diameter X 10 in. long
1 Welding rod of Aluminum, 1/8 in. diameter X 10 in. long
1 Welding rod of steel, 1/8 in. diameter X 10 in. long
1 Welding rod of drill rod, 1/8 in. diameter X 10 in. long
1 Hack saw blade

PROCEDURE

1. The following is a step-by-step procedure for the operation of the hardness tester.
   A. Insert a **1/16 in. diameter ball penetrator** in the machine.
   B. Make sure there is **100 kgm major load** on the rear of the machine.
   C. Make sure the load lever on the right of the machine is fully forward.
   D. Place the specimen on the anvil and raise the anvil until it touches the penetrator.
   E. Continue to raise the anvil until both dials are straight up.
   F. After the penetrator has touched the material do not lower the anvil.
   G. The face of the dial can be adjusted so that the big needle is at the set/set point.
   H. **Release the major load** by tripping the lever on the right.
   I. The big needle will now move to some position. The needle will stop moving in about 15 seconds.
   J. Now remove the major load by pulling the load lever forward.
   K. The big needle will now move to the hardness number of the specimen.
   L. Read the **hardness number from the B scale.**
   M. To remove the specimen, turn the hand wheel counter clockwise until the penetrator is no longer in contact.
   N. The hardness tester is now ready to take another hardness test.
   O. To use **the C scale replace the 1/16 steel ball with the diamond cone and add 50 kgms, and read the C scale.**
   P. Be sure both top and bottom of the specimen are flat and clean before taking a hardness test.

2. To become familiar with Rockwell hardness testing requires the use of the machine. Take a Rockwell hardness test on the following metals and record in table 2. Take three readings on each and average the hardness number.
   A. Yellow Brass – Rockwell B
   B. 2024-T6 aluminum – Rockwell B
   C. 1018 steel – Rockwell B
   D. 304 stainless – Rockwell B and C
   E. Drill rod – Rockwell C
   F. Tool steel – Rockwell C
   G. Tongue of file – Rockwell C
   H. Body of file – Rockwell C
   I. Two unknown specimens

3. This step is to relate the hardness of a material with its strength. Grasp one of the 1/8 in. diameter rods with both hands, thumbs close together, and try to bend through 90°. Record the ease of bending in table 2. Try bending the following rods.
   A. Yellow brass
   B. Aluminum
   C. Steel
   D. Stainless
   E. Drill rod
   F. One of the unknowns

   If the specimen brakes, this means it is too brittle or too hard to be plastically deformed.

4. With a hand-held hack saw blade, try cutting the specimens in part 2. Record how easily they cut in table 2. **NOTE: Start with the softer specimens. If you start by sawing on the file, you will wipe the teeth off the hack saw blade.**

Specimen	Rockwell B	Rockwell C	uts	Can you Bend*	Does Hack saw Cut**
A. Yellow Brass					
B. 2024-T6 Aluminum					
C. 1018 steel					
D. 304 Stainless					
E. Drill Rod					
F. Tool Steel					
G. Tongue of file					
H. Body of file					
I. Unknown					
J. Unknown					

Fig. 8-2 Table 2

ANALYSIS GUIDE. In analyzing the results of this experiment you should consider the hardness relationship of the various materials vs the ability to cut and bend the materials. Be sure you mention some fabrication properties of the two unknowns and discuss the relationship between hardness and tensile strength.

PROBLEMS

1. You have been given a piece of material and told to cut it into four pieces. By chance you decided to take a hardness test on the material. The material had a Rockwell C of 42. Will this material be easy to cut? Why?
2. If you were given a bar of aluminum, yellow brass, and stainless steel, which of the bars would be easiest to machine? Which the hardest to machine?
3. You are given a material of unknown hardness and told to find the hardness of this material. Should you take a Rockwell B or Rockwell C test first? Why?
4. Could you set up a hardness test by dropping a known weight a known distance and measuring the height of rebound? Explain.

experiment 9 HEAT TREATMENT OF STEEL

INTRODUCTION. Steel is one of the most widely used engineering materials. The reason for its use is that steel can be heat-treated to many desired mechanical properties. This experiment will deal with the changes of mechanical properties in steel by heat treatment.

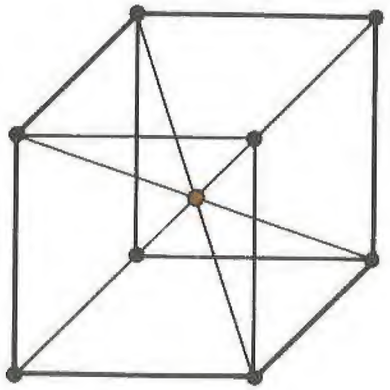
DISCUSSION. Steel is defined as an alloy of iron and carbon, plus some manganese, silicon, phosphorus and sulfur. The carbon in steel does not exist as free carbon. Instead, the carbon is combined with the iron as a iron carbide (Fe_3C). This compound, and its form, is what influences the properties of steel. We will be discussing the forms of this iron carbide later in this experiment.

Heat treatment is defined as heating the steel to a predetermined temperature and cooling at a predetermined rate. When steel is heated over its critical temperature, the atomic form changes. Steel at room temperature has a **body centered cubic (BCC) structure.** When heated above its critical temperature, this structure changes to a **face centered cubic (FCC) structure** as shown in figure 9-1.

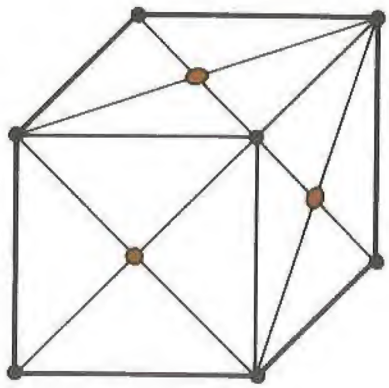
The BCC of steel is magnetic and the FCC of steel is nonmagnetic. This fact gives us a good indication of when we have heated steel above its critical temperature. This change will occur when the steel is approximately cherry red.

When steel cools, the structure changes back to a body centered cubic. This ability to change structures is called **allotropic transformation.** The allotropic transformation is what allows steels to be heat treated to change mechanical properties.

When steel is heated and cooled slowly (**annealing**), the iron and the iron carbide form ferrite and pearlite. **Ferrite** is iron plus impurities. **Pearlite** is a laminar structure of ferrite and iron carbide. This slowly-cooled structure is soft and has medium strength, depending on the percent of carbon.



(A)



(B)

Fig. 9-1 (A) Body Centered Cubic (BBC)
(B) Face Centered Cubic (FCC)

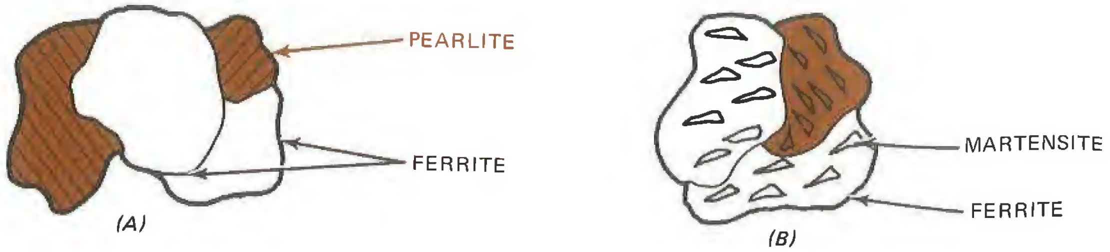


Fig. 9-2 (A) Annealed Steel (B) Hardened Steel

When steel is heated and cooled rapidly (**hardening**), the iron and iron carbide forms ferrite and martensite. **Martensite** is an acular form of iron carbide and is very hard and brittle, figure 9-2B. This rapidly-cooled structure in steel is hard and brittle with high strength. When the steel is heated to above its critical temperature the atomic form changes to FCC. When cooled rapidly, the steel must revert back to BCC. When this happens at low temperatures, many internal stresses are induced into the steel. These stresses make the steel hard and brittle.

To relieve these stresses the steel must be reheated (**tempering**) to some temperature below the critical temperature. This reheating reduces hardness and brittleness of the quenched steel. By reducing brittleness, the steel becomes tougher. The structure produced is called a **tempered martensite.** The temperature to which the steel is reheated determines the properties of the steel. The table in figure 9-3 shows some of these properties of a 0.4% carbon steel. The colors in this table are temper colors. They show up when heating a steel that has been polished. These colors give a good indication of reheating temperatures.

In conclusion we can say that the hardness of steel depends upon the percent of carbon and the cooling rate. If a steel is cooled slowly it will be soft, if rapidly the steel will be hard. Therefore, the rate of cooling is important in fabrication processes.

Condition, °F	Rockwell C	Toughness*
As quenched	C – 54	2
450° straw	C – 51	5
520° bronze	C – 48	7
590° blue	C – 46	12
640° light blue	C – 42	30
720° gray	C – 37	49
800° – – – –	C – 30	55
*Larger numbers – tougher		

Fig. 9-3 Properties of 0.4% Carbon Steel

MATERIALS

- 6 Steel samples 1/2 in. X 1/2 in., 1010, 1020, 1030, 1040, 1060 and 1090
- 1 Oxyacetylene torch (only one needed for entire lab)
- 2 Fire bricks
- 1 Five gallon water container
- 1 Magnet
- 1 Rockwell hardness tester (only one needed for entire lab)
- 1 Sheet emery paper, 300 grit
- 4 Steel samples 1/4 X 1/4 X 2 in. square
- 1 Vice
- 1 Ball peen hammer 1/2 lb

PROCEDURE

1. Place the samples of 1010, 1020, 1030, 1040, 1060 and 1090 steel on the fire bricks.
2. With the oxyacetylene torch heat each sample red-hot. Check with the magnet to make sure the samples are nonmagnetic.
3. As quickly as possible, quench each sample in water. **Agitate the sample in the water while cooling.**
4. After the samples have cooled, clean the surfaces with emery paper in preparation for hardness test.
5. Take Rockwell C hardness tests on each sample and record in the Data Table, figure 9-4.
6. With this data, now plot Rockwell C versus % carbon.
7. Heat and quench four 1/4 X 1/4 X 2 in. long bars of 1040 steel as in steps two and three.
8. Clean each of the specimens with emery paper.
9. Leave one specimen in the "as quenched" condition.
10. Place one of the quenched specimens on the fire bricks and heat by playing the flame over the entire specimen until it turns to a straw color. **Then quench the specimen to stop the heating process.**
11. Do the same for another specimen except heat to a blue color. Then heat the third specimen to a gray color.
12. Take a Rockwell C hardness test on all four specimens and record in the Data Table.
13. Clamp each specimen in a vice with one inch protruding out of the vice.
14. We now want to find the approximate toughness of each specimen. Strike each specimen with the hammer and estimate how much energy is required to break the specimens. Record number of blows to break the specimen in the Data Table.
15. Plot Rockwell C hardness versus tempering temperature.

ANALYSIS GUIDE. In analyzing the results of this experiment you should consider the two graphs. Also you should consider how other properties are affected by heat treating a steel.

Specimen	Rockwell C
1010	
1020	
1030	
1040	
1060	
1090	

Specimen	Rockwell C	Toughness*
As quenched, Not Reheated		
Reheated Straw, 450° F		
Reheated Blue, 590° F		
Reheated Gray, 720° F		

*Record number of blows

Fig. 9-4 The Data Tables

PROBLEMS

1. If you are sharpening a drill and the end you are grinding turns blue, how has this affected the drill?
2. Arc welding heats steel quickly and cools it rapidly by heat dissipation through the metal. Therefore, will an area next to the weld in a 1040 steel be hard or soft?
3. If a steel is heated above its critical temperature, it can be cooled at any rate without changing the properties of the steel. Is this statement true or false and why?
4. Will a steel that has been tempered to 400° F be tougher than one tempered to 800° F?
5. Did some of the specimens in part four of this experiment crack? If so, why?

experiment 10 ALUMINUM AND ALUMINUM ALLOYS

INTRODUCTION. Aluminum is a very useful engineering material. Therefore, we should look at some properties of aluminum, how they can be used, and how aluminum alloys can be heat-treated.

DISCUSSION. The use of aluminum as an engineering material can be attributed to its mechanical and physical properties. Some of the physical properties are:

A. Light weight – 1/3 that of steel.
B. Good corrosion resistance – forms a thin transparent oxide film on the surface.
C. Good electrical conductivity – 60% that of copper.
D. An efficient reflector of light and heat.

Some of the mechanical properties of aluminum are:

A. A ductile metal that can be formed easily.
B. Alloys have very good strength.
C. Some alloys can be strengthened by heat treatment.

Aluminum in its pure state has low mechanical properties. Therefore, aluminum alloys are the most widely used form of aluminum. The common designation of aluminum alloys follows a four digit system. The first digit indicates the alloy group, the second the alloy modification, and the last two digits the old classification. Figure 10-1 gives this classification.

Following the four digit number is the temper designation. This designation is in two general categories; non-heat treatable and heat treatable as shown in figure 10-1.

Alloy Designation	
1XXX	99% Aluminum
2XXX	Al-Copper
3XXX	Al-Manganese
4XXX	Al-Silicon
5XXX	Al-Magnesium
6XXX	Al-Magnesium-silicon
7XXX	Al-Zinc
	AL-others

Temper Designation	
0	Annealed
H	Strain hardened
H1	Strain hardened only
H2	Strain hardened and partially annealed
T	Heat treated
T3	Solution heat treated and cold worked
T4	Solution heat treated and naturally aged
T6	Solution heat treated and artificially aged

Fig. 10-1 Aluminum Alloy Designations

The non-heat treatable alloys are followed by either an "O" or "H". The "H" designation shows the alloy has been cold-worked to some hardness and strength. Two alloys of this type are the 3XXX-H and 5XXX-H. The "O" means the alloy has been annealed.

The heat treatable alloys are followed by the "T" designation. The common heat treated alloys are the 2XXX-T, 6XXX-T, and the 7XXX-T series. The heat treatment of aluminum alloys differs completely from that of steels. Aluminum alloys are solid solution heat-treated. That is, the alloy is heated to some pre-determined temperature and then quenched. This produces a very soft structure. The alloy is then reheated to allow precipitation of compounds. When precipitation occurs, the alloy becomes harder and stronger. This type of heat treatment is called solid solution heat treatment and precipitation hardening. For some alloys this precipitation of compounds will occur at room temperature. This is called natural aging. Artificial aging means you must heat the aluminum to some temperature to cause precipitation of the compounds.

The 2024-T aluminum alloy is a good example of solid solution heat treatment. If this alloy is heated to approximately 920°F and quenched in ice water, it will be soft. By reheating the alloy to 200°F, precipitation of the aluminum copper compounds will occur and the alloy will become hard and strong. This 2024-T alloy is also a natural aging alloy. That is, if the 2024-T alloy is quenched and then left at room temperature, it will naturally age in about two days to full hardness.

Some properties of the aluminum alloys are as follows:

1XXX series — Pure aluminum — low strength and hardness — used for electrical conductors.

2XXX series — Solid solution heat treatable to good strength levels — possesses good ductility — best strength by precipitation hardening.

3XXX series — Non-heat treatable — stronger than pure aluminum — easily fabricated.

4XXX series — High silicon — low melting range — good fluidity — good casting aluminum alloy.

5XXX series — Non-heat treatable — moderate strength, excellent corrosion resistance and good forming properties — good welding ability.

6XXX series — A heat treatable alloy — lower strength than 2XXX series — better ductility.

7XXX series — The strongest aluminum alloy — not ductile — low corrosion resistance.

MATERIALS

3 Pieces of 2024 aluminum, 1 in. diameter X 1/2 in. thick
1 Rockwell B hardness tester
2 Fire bricks
1 Oxyacetylene welding torch
1 Pint 200°F hot water
1 Gallon ice water

PROCEDURE

1. Select two 1 in. diameter by 1/2 in. thick pieces of 2024 aluminum.

2. Take a RB hardness test on each piece and record in Table 1.
3. Place the aluminum on two fire bricks and prepare for heating the specimens.
4. Adjust the oxyacetylene flame where it is producing a small amount of black smoke. Play the flame over the aluminum until it turns black.
5. Adjust the flame to a neutral flame and heat the specimens. When the black smoke leaves the specimens, they have been heated to about 900° F.
6. Rapidly quench one of the specimens in ice water. Leave the other specimen to cool in the air.
7. Quickly move to the Rockwell B hardness tester. Take one hardness test on the quenched specimen and record in Table 1.
8. Leave the specimen at room temperature.
9. Start taking a hardness test on the quenched specimen every 2 minutes for 10 minutes, then every 5 minutes for 20 minutes, and then every 15 minutes until the end of the lab period. Record the data in Table 2.
10. While waiting to take the hardness tests, repeat steps 3 to 6 for another sample of 2024 aluminum.
11. After quenching this sample, take a hardness test and place the sample in hot water. Record the hardness in Table 1.
12. Repeat step 9 for this sample in hot water and record in Table 3.
13. After the sample that was slowly cooled, in step 6, has cooled enough to handle, take a hardness test and record in Table 1.
14. Take a hardness test on this sample about every 30 minutes until the end of the lab. Record time and hardness test in Table 4.
15. Plot Rockwell B vs time from Tables 1, 2, 3, and 4. Note that Table 1 gives the quenched or zero time reading. You may not be able to plot all the time values. Just note the trend of the graphs.

Specimen	Rockwell B
Step 2 as received	
Step 7 as quenched	
Step 11 as quenched	
Step 13 air-cooled	

Table 1

Fig. 10-2 Experimental Data

time	RB	time	RB	time	RB
2		15		50	
4		20		65	
6		25		80	
8		30		95	
10		35		110	

Table 2 After Quenching – Left at Room Temperature

time	RB	time	RB	time	RB
2		15		50	
4		20		65	
6		25		80	
8		30		95	
10		35		110	

Table 3 After Quenching – Left in Hot Water

time	RB	time	RB	time	RB
2		15		50	
4		20		65	
6		25		80	
8		30		95	
10		35		110	

Table 4 Air-Cooled

Fig. 10-2 Experimental Data (Cont'd)

ANALYSIS GUIDE. To analyze this experiment you should observe what has happened to the hardness of the heat-treated 2024 aluminum. The plot in step 15 of the procedure will show the hardness changes.

PROBLEMS

1. Can a 2024-T4 aluminum alloy be reheated to increase its hardness and strength?
2. Explain the alloy and temper designation of (a) 5052-H2 and (b) 6061-T6.
3. Explain what happened to the 2024 aluminum alloy when it was put in hot water in step 11 of the procedure.
4. Will the hardness of the 2024 aluminum alloy exceed the hardness of the "as received" alloy?
5. Name an aluminum alloy that has the following properties: (a) highest strength, (b) best corrosion resistance, (c) best ductility and heat treatability.

experiment **11** CORROSION

INTRODUCTION. The reaction of metals with their environment is an ever-pressing problem. By understanding the nature of corrosion we can eliminate some of the corrosion problems that occur.

DISCUSSION. Electrochemical corrosion will occur any time metals are in a corrosive environment. If only one metal is involved, this is called **uniform corrosion**; that is, **corrosion over the entire surface.**

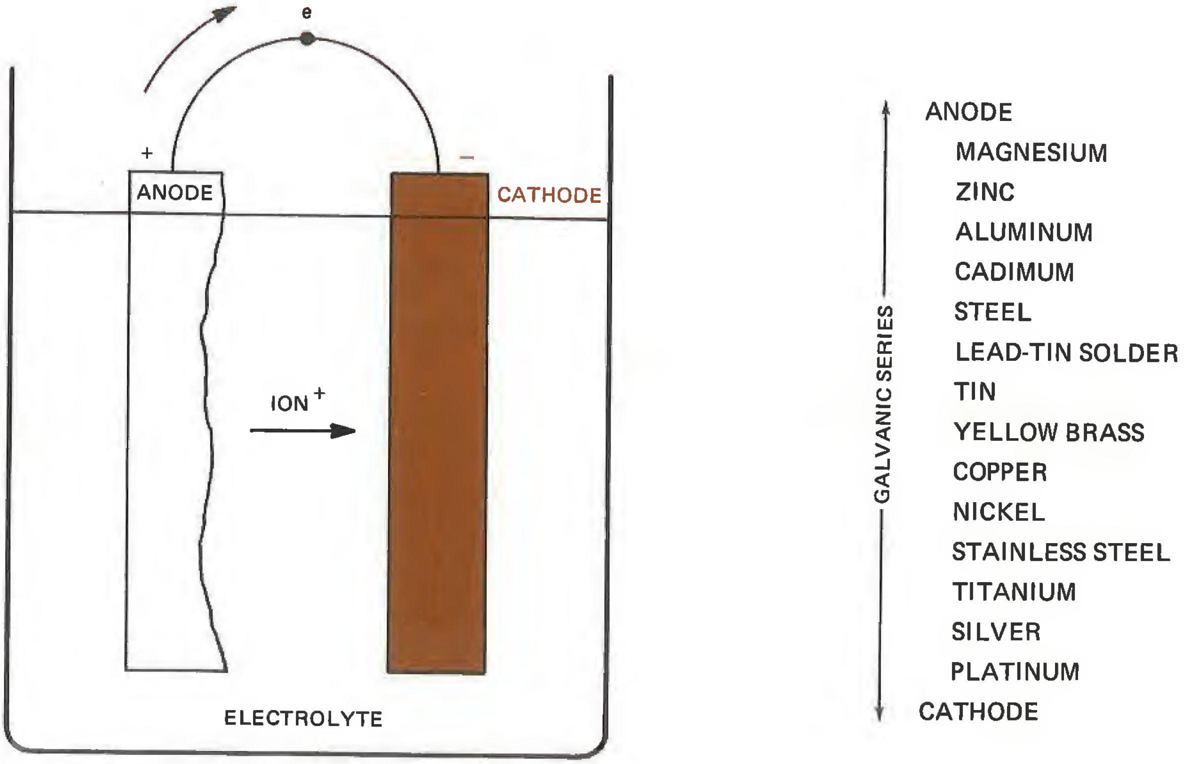
However, when two dissimilar metals are in contact in an electrolyte, a galvanic couple is produced and corrosion results according to the galvanic series of figure 11-1B. **The most active corrosion occurs with metals that are on the extreme ends of the list.**

A. Two different metals

B. The metals must be in electrical contact

C. The metals must be in an electrolyte (a solution containing ions)

Figure 11-1A shows two metals in an electrolyte where one metal becomes the anode (–) and the other the cathode (+).



(A) *(B)*

Fig. 11-1 (A) Galvanic Cell and (B) Galvanic Series

The electrons flow from the anode to the cathode in the external circuit and positive ions flow through the solution. When the ions leave the anode, metal is lost to the solution. This metal ion goes into the solution and is oxidized, thus consuming the anode. The electrons leaving the anode through the external circuit travel to the cathode. At the cathode, electrons enter the electrolyte and neutralize hydrogen ions, and the hydrogen usually leaves the cathode as a gas. The anodic reaction for an iron anode is

$$Fe \rightarrow Fe^{++} + 2e^{-}$$

and the cathodic reaction (for copper) is

$$H_2O + 2e^{-} + 1/2\ O_2 \rightarrow 2(OH)$$

The flow of electrons in the external circuit can be observed by placing a millivoltmeter in the circuit between the anode and cathode. This current is the result of the voltage produced between the two metals in an electrolyte. The magnitude of this voltage depends on how far apart the two metals are in the galvanic series. For example, **the greatest voltage will result between magnesium and platinum.** The greater the potential between any two metals, the more susceptible they are to corrosion.

The size of the anode and cathode also determines the rate of corrosion. When a large anode is connected to a small cathode, the rate of corrosion is small. Conversely, **rapid corrosion occurs when a small anode is connected to a large cathode.** A small anode must supply many electrons to the large cathode. Therefore, the anode must release many metal ions to the solution and the anode is rapidly consumed.

The anode-cathode effect can also be produced in one metal. Areas of one metal can be anodic with respect to other areas. If one area of a metal is stressed, cold worked, heat-treated, or loaded, it becomes anodic. Therefore, this stressed area (anodic area) suffers corrosion. This corrosion can be very detrimental because corrosion usually leaves pits or notches which reduce the strength of the structure.

The prevention of corrosion can be accomplished by selecting metals properly or by surface protection. When selecting metals, it is important to observe the galvanic series and the small anode-large cathode effect. Surface protection can be anything from paint to metal plating. Plating a metal with another metal that is more anodic will restrict corrosion. In some metals, oxide films are produced to prevent further oxidation. Some metals, like aluminum, produce their own oxide films. This oxide film must be retained in these metals because low oxygen concentrations produce an anodic area. This is why corrosion sometimes occurs under the head of a bolt or washer where oxygen is restricted.

Protection of a structure can be accomplished by using an expendable anode. This is called cathodic protection. By placing a metal that is more anodic in electrical contact with a structure, the anode will corrode. This anode is then replaced when it is consumed. An example of this is the magnesium anode in hot water heaters.

MATERIALS

1 in. X 3 in. pieces 1/32 in. thick or less with one 1/4 in. hole in the end of the 1 in. width of the following:

2 Pieces of sheet aluminum
3 Pieces of sheet magnesium
3 Pieces of sheet steel
2 Pieces of sheet copper

1 in. X 3 in. pieces 1/32 in. thick or less with two 1/4 in. holes near the center of the sheet of the following:

1 Piece 1 in. X 6 in. of sheet steel
1 Piece 1 in. X 6 in. of sheet aluminum
1 Piece 1 in. X 6 in. of sheet magnesium
1 Piece 1 in. X 6 in. of sheet zinc
1 Piece 1 in. X 6 in. of sheet stainless steel
1 Piece 1 in. X 6 in. of sheet tin
1 Piece 1 in. X 6 in. of sheet copper
1 Piece 2 in. X 6 in. of sheet copper
1 Piece 2 in. X 6 in. of sheet steel
1 Piece 1/4 in. X 6 in. of sheet copper
1 Piece 1/4 in. X 6 in. of sheet steel

5 Each, 1/4-20 steel bolts 1/4 in. long, with nuts
2 Each, 1/4-20 copper bolts 1/4 in long, with nuts
1 Each, 250 ML beaker
2 Tablespoons salt
1 Piece of platinum wire
1 Millivolt meter — 0 to 1.5 volts

PROCEDURE

1. Select the metals listed below and bolt the two metals together using the 1/4-20 steel bolts. After tightening the nuts, bend the two metals so that they are only touching at the bolt.
   A. Magnesium to steel
   B. Magnesium to aluminum
   C. Steel to copper
2. Select the copper plate and two 1/4-20 steel bolts and nuts. Insert bolts and tighten the nuts.
3. Select the steel plate and two copper or brass 1/4-20 bolts and nuts. Insert bolts and tighten the nuts.
4. Select one piece, 1 X 3 in., of steel, aluminum, magnesium, and copper.
5. All of the metals in the above procedure are now to be taken to some corrosive environment and left for three weeks. The metals can be buried outside the lab. Use your knowledge of corrosion and predict the results for each combination.
6. Mix up a salt water solution of one pint water and two tablespoons of salt. Pour this solution into the 250 ML beaker.
7. Put one 1 in. strip of steel and one 1 in. strip of magnesium in the salt solution.

8. Connect one lead of the millivolt meter to the steel and the other lead to the magnesium. The meter should move to some voltage. **If the meter moves in the wrong direction, reverse the leads.** Mark the lead connected to the steel (+) cathode.
9. Record, in Table 2, voltage readings for the magnesium-steel couple. Then replace the magnesium with one other metal. **NOTE: If the voltmeter moves in the wrong direction, change the leads and record a negative voltage. Be sure to reconnect the positive lead to the steel.**
10. Record in Table 2 the readings for the other metals, (section 2 of the material list) connected to the steel.
11. Connect a 2 in. wide copper sheet to the positive lead and a 1/4 in. wide steel sheet to the negative lead. Put the copper and steel in the salt solution. Wait approximately 2 minutes and read the voltage produced.
12. Repeat step 11 except use a 2 in. wide steel sheet and a 1/4 in. wide copper sheet.
13. Record the voltages from steps 11 and 12 in Table 3.
14. After three weeks remove the metals in step 5 and observe the corrosion that has occurred and compare with the predicted results.

ANALYSIS GUIDE. In analyzing the data obtained in this experiment you should discuss the rate of corrosion of a two metal couple when:

A. The metals are close together in the galvanic series.
B. The metals are far apart in the galvanic series.

You should also discuss the effect of size of anode and cathode.

Metal	Voltage
Magnesium	
Zinc	
Aluminum	
Steel	
Lead	
Tin	
Copper	
Stainless	
Platinum	

Table 1

Fig. 11-2 The Data Tables

Couple	Voltage
2 in. wide copper 1/4 in. wide steel	
1/4 in. wide copper 2 in. wide steel	

Table 2

Fig. 11-2 The Data Tables (Cont'd)

PROBLEMS

1. How could you prevent corrosion in a steel structure that is already in service in a corrosive environment?
2. You are trying to select a coating for steel to protect it against corrosion. Assume the coating will get broken with a pipe wrench when installed. Which would you select, zinc or tin, and why?
3. If aluminum cans were coated on the outside with a thin coating of magnesium, would they last longer than pure aluminum cans?
4. Would an aluminum part or a copper part be easier to remove from a corroded steel pipe?
5. Why do the steel bolts in a steel structure usually corrode first?

experiment 12 THERMOPLASTICS

INTRODUCTION. Plastics have become a very important material in our society today. It seems that everything is made of plastic. This experiment is designed to help you become more familiar with several types of plastics. The proper identification of plastic is important when you need to fabricate or repair a part made of plastic.

DISCUSSION. There are many different types of plastics with many different properties. There is no one plastic that will completely meet every property requirement. Therefore, we must know quite a variety of plastics and their properties.

First we need to define a plastic. Most plastics are hydrocarbons combined in such a manner to produce a solid material with specific properties. A stable hydrocarbon, $C_nH_{2(n+1)}$, follows this formula. Two stable hydrocarbons are methane, CH_4, and ethane, C_2H_6. There are also unstable hydrocarbons such as ethylene, C_2H_4, and very unstable acetylene, C_2H_2. If two or more molecules of a hydrocarbon are combined to form a larger molecule, this is called polymerization. The product of polymerization is a polymer. A good example of a polymer is polyethylene which is produced by polymerizing ethylene.

Traditionally, plastics are divided into two broad classifications: thermoplastics and thermosetting plastics. Thermoplastics can be softened by heat and reformed into another shape. Thermosetting plastics will not soften by heat. They will only burn or char when heated.

The largest classification of plastics are the thermoplastics. For now we will limit our discussion to thermoplastics. By knowing some of the properties of various thermoplastics, we can select and use these plastics to our advantage.

Acetals (Dupont's Delrin). The acetals are one of the strongest and stiffest thermoplastics. They also have such outstanding properties as: low coefficients of friction (feel slippery), exceptional solvent resistance, good dimensional stability, and high heat resistance up to 220°F.

Acrylics. This plastic has outstanding resistance to long-term exposure to sunlight, heat and weathering. Therefore, it is good for outdoor applications. Acrylics have excellent optical properties and better impact strength than glass. They do not have good abrasion resistance and therefore scratch easily. The general application of acrylics is made for its optical properties and its fair strength, low water absorption, and good insulating properties.

Cellulosics. The cellulosics is a family of plastics that includes cellulose acetate, cellulose acetate butyrate, and others. This family of plastics is known for its good strength, toughness, transparency, and high surface gloss. The cellulosics have good chemical resistance but should not be used at temperatures above 170°F. These plastics will absorb moisture. Nearly all of the cellulosics are noted for their toughness, excellent moldability, and brilliant high gloss finish. Even though this family of plastics has good toughness, they are not primarily a load-bearing material.

Polyethylene. Polyethylenes are known because of their toughness, excellent chemical resistance and electrical insulating properties, near zero moisture absorption, low coefficient of friction, ease of processing and low price. Polyethylenes, in general, are not known for their load-carrying ability. Some can be used for short time loads. A part made of polyethylene under load can deform a great deal before failure will occur. This plastic can have a percentage of elongation over 200%. Few plastics have the excellent chemical resistance and dielectric properties of polyethylenes.

Polystyrene. This is a large family of plastics derived from the styrene monomer. Polystyrenes are known for their low cost, ease of processing, hardness, and excellent dielectrical and insulating properties. This family of plastics is usually specifically made to provide good mechanical, thermal, and chemical properties. Polystyrene is commonly used for both electrical and heat insulation.

Polyvinyl Chloride (PVC). The PVC plastics have a wide range of properties. In general they are tough, with high strength and abrasion resistance, exceptional resistance to chemicals and moisture, and good insulating properties. The PVC plastics can be either flexible or rigid depending on the type. The rigid PVC has a hardness like that of hard rubber with high impact strength. The flexible PVC has lower strength and hardness.

Nylons. In comparison with other thermoplastics, nylons have the highest tensile strength. Nylons also have good impact strength and high abrasion resistance. Nylons will not stretch or deform excessively under short time loads, therefore they retain their shape. Nylons will absorb moisture with only slight dimensional changes. Nylons have good resistance to most petroleum base products. The high strength, abrasion resistance and resistance to oils make nylon an excellent material for gears, cams, and other sliding contact devices.

Acrylonitrile-butadiene-styrene (ABS). The ABS plastics have properties depending upon the relative amount of the three ingredients used. In general the ABS plastic has good tensile and impact strength, good insulating properties, good resistance to weak chemicals, low water absorption, and excellent resistance to weathering. The ABS plastics have good mechanical properties and do not fail by rupturing, but yield plastically at stresses above their tensile stress. An impact failure will occur as a ductile, rather than a brittle, failure.

Fluorocarbons, TFE, tetrafluoroethylene. The fluorocarbons are the basic ethylene hydrocarbons that have fluorides and chlorides replacing the hydrogen atoms. The outstanding properties of these plastics are their inertness to chemicals, low coefficient of friction, nonsticking properties, a waxy feel, and good heat resistance. Mechanical properties of this plastic are normally low; therefore, they are used as a coating or are reinforced with fibers. Fluorocarbons do not really fit into the thermoplastic group because they do not soften with heat. Therefore, the processing of fluorocarbons differs from that of other plastics. Another outstanding property of this plastic is its ability to withstand heat. A good example is the teflon coating material called CFE (chlorotrifluorethylene).

The plastics in the preceeding discussion are by no means all of the plastics used in industry. These plastics are only some of the general plastics. To become more familiar

with these types of plastics we now need some method of distinguishing these plastics from each other. The following discussion will give some of the distinguishing factors of the plastics.

Burn testing is one method of distinguishing one plastic from another. A chemical analysis is the best method of distinguishing plastics, but a burn test is useful if you have a good sense of smell and some experience with plastics. This test is accomplished by burning a small piece of the plastic and observing the way the plastic burns. Special attention should be given to the color of the flame, ease of burning, how much smoke is produced, and the odor of the plastic after extinguishing the flame. By first getting some experience in burn testing known plastics, you should be able to distinguish some of the common unknown plastics.

The following is a list of plastics and their burn test features. The first thing to observe when heating a plastic is if it becomes soft after heating. If the plastic softens, it is a thermoplastic. If the plastic does not become soft, it is a thermosetting plastic.

Acetal. Hard to ignite, melts and then burns slowly with a small very blue flame, no smoke is produced, a very acid smell. (Caution - Do not inhale the fumes directly from the flame or from the extinguished flame. If you inhale the fumes from this plastic it will produce a burning sensation in your nose and you won't do it again.)

Acrylics. Softens, burns with a spitting sound, flame is blue at base with a yellow mantle, very little smoke, has a sweet distinctive odor.

Cellulose Acetate. Melts in a flame, burns with a hissing blowing sound and a slightly smokey flame, a smell of burnt vegetation on extinction, and leaves a charred hard black residue.

Polyethylene. Burns with a smoke free flame. Leaves a waxy smell on extinction, and will float on water.

Polystyrene. Softens and burns fairly readily with a yellow-white extremely sooty flame. A sweet odor of styrene on extinction.

Polyvinyl Chloride. Softens but does not burn without continued assistance. Produces a very sooty flame and black residue.

Nylon. Melts, darkens, boils, and finally burns with a small blue flame that is easily extinguished, leaving a white smoke and the odor of burning vegetation.

Fluorocarbons. Will not burn, melts, decomposes slowly with a white residue. Inhalation of the vapors is hazardous. (Produces a poison gas).

There are other distinguishing factors of plastics besides burn testing. Some of these factors are: softness, transparency, feels slippery, and others. With some experience handling known plastics, you should be able to recognize some of these distinguishing features.

MATERIALS

- 1 Piece of acetal, 1/8 in. X 1 in. X 6 in.
- 1 Piece of acrylic, 1/8 in. X 1 in. X 6 in.
- 1 Piece of cellulose acetate, 1/8 in. X 1 in. X 6 in.
- 1 Piece of polyethylene, 1/8 in. X 1 in. X 6 in.
- 1 Piece of polystyrene, 1/8 in. X 1 in. X 6 in.
- 1 Piece of polyvinyl chloride, 1/8 in. X 1 in. X 6 in.
- 1 Piece of nylon, 1/8 in. X 1 in. X 6 in.
- 1 Piece of teflon, 1/8 in. X 1 in. X 6 in.
- 1 Piece unknown #1, 1/8 in. X 1 in. X 6 in.
- 1 Piece unknown #2, 1/8 in. X 1 in. X 6 in.
- 1 Bunsen Burner

PROCEDURE

1. Obtain samples of the following plastics and arrange in order from left to right on your work bench: acetal, acrylic, cellulose acetate, polyethylene, polystyrene, polyvinyl chloride, Nylon, and Teflon.
2. Light the bunsen burner and adjust to a small smoke-free flame.
3. Place a corner of the first plastic, acetal, in the flame for approximately five seconds; then remove from the flame. Note if the plastic has started to melt or burn. If it is burning, go to step 6.
4. If the plastic is not burning, place back in the flame for approximately 10 seconds. Then remove. Note if the plastic is burning. If it is burning, go to step 6.
5. If the plastic is not burning by now, hold the plastic in the flame until burning does occur.
6. While the plastic is burning note the characteristics of the flame. It may be necessary to extinguish the flame by blowing if burning is too rapid.
7. After extinguishing the flame note the odor of the fumes. (Caution - Do not smell the burning plastic or sniff the vapors directly from the plastic.)
8. Now list the characteristics of the flame in the Data Table 1.
9. Repeat steps 3 through 8 for each of the plastics listed in step 1.
10. After the burn test, pick up each plastic, break off a piece, and observe visually any distinguishing characteristics of the plastic. (Hardness, transparency, feel, type of failure, etc.)
11. Record any visual characteristics in Table 2.
12. Repeat steps 3 through 8 and step 10 for each of the unknown plastics and record your observations in Tables 1 and 2.

Flame Test Characteristics of the Plastics

A. **Ease of ignition** - fast, slow, very slow

B. **Burning Rate** - fast, slow, very slow

C. **Flame Size** - large, small, very small

D. **Color of Flame** - blue, yellow, etc.

E. **Amount of Smoke** - none, slightly smokey, very smokey

F. **Odor After Extinguishing** - relate the odor of the vapors to odors you know.

G. **Other observed characteristics of the flame.**

	A	B	C	D	E	F	G
Plastic	Ease of Ignition	Burning Rate	Flame Size	Color of Flame	Amount of Smoke	Odor	Other
1. Acetal							
2. Acrylic							
3. Cellulose Acetate							
4. Polyethylene							
5. Polystyrene							
6. PVC							
7. Nylon							
8. Teflon							
9. Unknown #1							
10. Unknown #2							

Fig. 12-1 Experimental Data, Flame Test

Plastic	Visual Characteristics
1. Acetal	
2. Acrylic	
3. Cellulose Acetate	
4. Polyethylene	
5. Polystyrene	
6. PVC	
7. Nylon	
8. Teflon	
9. Unknown #1	
10. Unknown #2	

Fig. 12-2 Experimental Data, Visual Characteristics after Burning

ANALYSIS GUIDE. The best way to analyze this experiment is to determine the name of an unknown plastic. What type of plastic is your tooth brush made of and why do you think so. Give a brief summary of the results of this experiment.

PROBLEMS

1. Which of the plastics in the discussion would you select for:

   A. Heavy loads
   B. Transparency
   C. Lowest cost

2. If you heated a plastic and it didn't soften, what type of plastic would it be?
3. Name two plastics that could be used in a variety of strong chemicals.
4. Fluoride and chloride gases are very dangerous to inhale. Which of the plastics would produce these gases when burned?

experiment 13 THERMOSETTING PLASTICS, PLASTIC ADHESIVES AND POTTING COMPOUNDS

INTRODUCTION. This experiment is intended to encourage you to continue your search for useful plastics. Some knowledge of thermosetting plastics, adhesives, and potting compounds will increase your knowledge of the applications of plastic materials.

DISCUSSION. This experiment will be concerned with thermosetting plastics and bonding compounds. We know that thermosetting plastics will not soften by heating because most thermosetting plastics have strong cross-linking bonds which are destroyed by heat. There are not as many thermosetting plastics as there are thermoplastics. Therefore, we will restrict our discussion to only three thermosetting plastics.

The production of a thermosetting plastic occurs in certain steps. Some thermosets need two steps while others require three steps. The first step is to produce a thermoset in a liquid form. The second step is either heating this liquid or mixing the resin with a catalyst. This second step, in some thermosets, produces the final form reaction, as in the case of the epoxy, while other thermosets need a third step of heating and cooling to produce the final reaction (phenolic).

Phenolic. This plastic starts off as a phenol-formaldehyde resin. Phenolic requires a reheating of step two to produce its final form. Heating after the third step destroys the phenolic plastic. When molded and cured, a phenolic product is very hard, rigid, inert to most chemicals, non-inflammable (self-extinquishing), and mostly dark in color. The phenolics, trade name bakelite, can withstand fairly high temperatures and have excellent insulating properties. The phenolic resins are used with paper cloth or other fibers to produce laminated sheets, tubes, rods or other shapes. The phenolic plastic is one of the oldest thermosetting plastics.

Epoxy. This plastic has more applications than almost any other plastic because of its versatility. It is used in the areas of castings, adhesions, encapsulating, moldings, surface coatings, and many others. This high use is partly due to the ease of producing a final shape by mixing liquid resin with a hardener. After this mixing, the epoxy will take its final shape in a short period of time, depending on the amount and type of hardener used. Some properties of the epoxies are: good strength, good wetting and adhesion to metal and glass fibers, will cure without external heat, low shrinkage during cure and good resistance to caustics and chemicals. These properties make the plastic a good adhesive for most materials.

Silicones. These plastics are not hydrocarbons, but instead are silicon-oxygen compounds. These plastics can be obtained as a liquid, a semi-solid or a solid depending on the amount of catalyst used. The following properties make the silicones a very useful plastic: good resistance to heat (500°), resistant to oxidation and oxidizing compounds, water repellent, little change in properties when heated, very good non-sticky characteristics, and excellent insulating properties. To get a better feel for the silicone plastics we will now look at their uses.

1. **Silicone fluids** - mold release agents, lubricants
2. **Silicone resins** - heat and electrical insulation

3. **Cold-cure silicone rubbers** - good insulation

4. **Bouncing putty** - elastic, brittle if suddenly loaded, exhibits cold flow

5. **Pharmacy and medicine** - barrier for moisture, body transplants

6. **Defoaming properties** - hydraulic fluid, water fountains

7. **Electrical** - good dielectric properties, remarkable thermal stability

8. **Water and stain repellent for textiles**

Adhesives. Another useful class of plastic materials are the adhesives. Some of the first plastic adhesives were the phenolics. The phenolics have the advantage of low cost but must be heat-cured. The development of high performance adhesives such as silicones, epoxies, and the urethanes has changed the application of adhesives. These plastics are now used where screws, bolts, and rivets were previously used.

Adhesives are available in several forms: 1. Powders dissolved by solvents; 2. Solvents that melt the plastic and then evaporate; 3. Meltable films; 4. Two component packages of resin compounds and curing agents.

The use of a solvent that melts the plastic and then evaporates is limited to only a few thermoplastics. This method produces a very good bond between like plastics. It has a limited use in bonding two dissimilar plastics. A general list of plastics and the solvents used is shown in the table.

PLASTIC	SOLVENTS
Acrylic	Methylene chloride – Ethylene dichloride, 100% glacial acetic acid
Cellulose Acetate	Acetone, Ethylene dichloride
Nylon	Normally not cemented by solvent
Polystyrene	Methylene chloride, Ethylene dichloride, trichloroethylene
Polyvinyl Chloride	Acetone, Cyclohexanone, Ethylene dichloride
Polyethylene	Solvent type cements are not applicable

In some cases thermoplastics can be heated so they will melt enough to be fused together. Applying a small amount of solvent to the surfaces to be bonded sometimes facilitates the process. Those plastics that can be heat-bonded are vinyl, polyethylene, polystyrene, nylon, acrylics, cellulose acetate, and polyvinyl chloride.

The use of a two-part resin has become a very useful process for bonding two different types of materials together. The epoxies demonstrate this type of adhesive. Some of these epoxies will cure at room temperature, but for maximum strength and heat resistance, they should be heat-cured. Epoxy adhesives can be used to bond glass, metal, ceramics, wood, and many plastics. They are not recommended for polyethylene, teflon, or silicone rubbers. One advantage of the epoxies is that they need practically no pressure during setting.

Casting Resins and Potting Compounds. Almost all of the thermoplastics and thermosetting plastics can be used as casting resins. The resin can be cast hot or cold by simply pouring it into a suitable mold and allowing it to solidify. These plastic compounds can be cast clear or white, or colored any color. Potting compounds are similar in composition to casting resins but are usually formed by cold casting. Potting compounds find many applications in the electronic field for enclosing electronic parts. This prevents damage from handling and the environment. Encapsulating is a technique for insulating electronic components by dipping the assembled part or component in a potting compound. The silicones are one of the newer plastics used for encapsulating. Another type of potting compound is foams. Foams, in general, involve the addition of a gaseous blowing agent at the opportune time in the setting process such that gas bubbles are trapped in the set-up plastic. Polystyrene and polyurethane are two of the most common foamed plastics. Almost all of the plastics can be foamed by introducing the gas into the plastic at the proper time.

MATERIALS

- 2 Pieces of acrylic plastic, 1/8 in. X 1 in. X 4 in.
- 2 Pieces of cellulose acetate, 1/8 in. X 1 in. X 4 in.
- 2 Pieces of polystyrene, 1/8 in. X 1 in. X 4 in.
- 2 Pieces of polyvinyl chloride, 1/8 in. X 1 in. X 4 in.
- 2 Pieces of polyethylene, 1/8 in. X 1 in. X 4 in.
- 10 Small rubber bands
- 1 Small dropping bottle of methylene chloride
- 1 Small dropping bottle of ethylene dichloride
- 1 Small dropping bottle of acetone
- 1 Small dropping bottle of trichloroethylene
- 1 Small dropping bottle of cyclohexanone
- 1 Piece of acrylic, 1/8 in. X 1 in. X 3 in.
- 1 Piece of cellulose acetate, 1/8 in. X 1 in. X 8 in.
- 1 Piece of nylon, 1/8 in. X 1 in. X 3 in.
- 1 Piece of polystyrene, 1/8 in. X 1 in. X 3 in.
- 1 Piece of polyvinyl chloride, 1/8 in. X 1 in. X 3 in.
- 1 Piece of polyethylene, 1/8 in. X 1 in. X 3 in.
- 1 Bunsen burner
- 2 Pieces of polystyrene, 1/8 in. X 1 in. X 2 in.
- 2 Pieces of polyethylene, 1/8 in. X 1 in. X 2 in.

PROCEDURE

1. **Caution: In this experiment you will be using some toxic solvents. Try not to breathe the fumes directly from their containers.**

2. Select two pieces 1/8 in. X 1 in. X 4 in. of acrylic plastic and the dropping bottle containing ethylene dichloride.

3. Drop about two drops of the solvent on about one-inch length of each piece of the acrylic plastic.

4. Place the two pieces on top of each other where the solvent was dropped and press together

5. Hold the pieces together for about one minute, or until the solvent sets. Blowing on the solvent will speed up the evaporation time. It may be necessary to wrap a rubber band around the specimens to hold them together.

6. The final set up will take some time so place the bonded specimen on your table and continue on.

7. Repeat steps 2 through 6 using polystyrene and the solvent of trichloroethylene.

8. Repeat steps 2 through 6 using polyvinyl chloride and the solvent of cyclohexanone.

9. Place one 1/8 in. X 1 in. X 2 in. piece of the following plastics next to each other with the 1-in. sides together; acrylic, cellulose acetate, nylon, polystyrene, polyvinyl chloride, and polyethylene.

10. On the lefthand side of each of the above plastics, place one drop of methylene chloride solvent.

11. To the right of the methylene chloride place one drop of ethylene chloride.

12. Repeat step 11 for acetone, trichloroethylene, and cyclohexanone.

13. Observe each drop of solvent on each type of plastic. If the solvent is softening or dissolving the plastic, write "yes" in proper blank in Table 1. If the solvent does not affect the plastic, write "no" in the blank.

14. Select two pieces of polystyrene, 1/8 in. X 1 in. X 2 in.

15. Hold the 1/8 in. X 1 in. edges near the bunsen burner until the edges start to melt. **If the plastic starts burning, quickly blow it out.** When the edges are liquid or very soft, butt the two pieces together. Hold the two pieces together until they cool and harden.

16. Repeat steps 14 and 15 using the two 1/8 in. X 1 in. X 2 in. pieces of polyethylene.

17. By now the pieces of plastic in steps 2, 7, and 8 should be dried. Try twisting the specimens to see how strong the bond has become.

18. Now twist the specimens in steps 14 and 15 to determine how strong the bond has become.

ANALYSIS GUIDE. In analyzing this experiment you should list some advantages and disadvantages in using solvent-type adhesives. You should also compare the strength of solvent adhesives versus heat bonding.

Plastic	SOLVENTS				
	Methylene Chloride	Ethylene Dichloride	Acetone	Trichloro-ethylene	Cyclohex-anone
Acrylic					
Cellulose Acetate					
Nylon					
Polystyrene					
Polyvinyl Chloride					
Polyethylene					

Yes - Solvent; No - Not Solvent

Fig. 13-1 Effect of Solvents on Plastics

PROBLEMS

1. Can heat bonding be used to prepare a broken part made of phenolic plastic? Why?
2. What is the difference between potting and encapsulating?
3. Can solvent bonding be used on polyethylene plastic?
4. What is the major advantage of epoxy over phenolic plastic as a potting compound when making a complete electronic plug-in board?
5. Could a procedure be devised to identify unknown plastics by dropping solvents on the unknown plastics?

experiment 14 COLD WORKING

INTRODUCTION. Cold working a metal is one of the methods used to change the mechanical properties of a metal. In general terms, cold working a metal increases the strength and decreases the ductility.

DISCUSSION. One of the properties that separates metal from other elements is its ability to be deformed plastically. Of the elements in the periodic table, three-fourths are metals. This plastic property is one of the most valuable characteristics of metals. It allows metals to be manufactured by rolling or drawing into strips, rods, tubes, and other structural shapes.

Cold working may be defined as plastic deformation at a temperature and rate such that strain hardening is produced. Metals can be cold worked because of their unique atomic structure of atoms stacked upon other atoms. These atoms are not rigidly attached to each other and can shift their atomic bonding without failure. Therefore, if a load is applied to a metal, the atoms can slip along particular planes of atoms. Once this slip has occurred, the metal becomes harder and stronger, and loses its ductility. By working a metal at a temperature such that this deformation is not removed, the metal remains strong and hard at room temperature. To remove the effects of cold working, the metal must be heated to its recrystallization temperature.

The arrangement of atoms in a metal affects the ease of fabrication of that metal. The atoms can be arranged either as a body-centered cubic, (BCC) face-centered cubic (FCC) or a close pack hexagonal structure. The metals with the BCC are the easiest to deform, the FCC is next, and the CPH has limited plastic properties.

Table one gives the metals and their atomic arrangement.

Metal	Arrangement
Aluminum	FCC
Copper	FCC
Yellow Brass	FCC
Steel (room temp.)	BCC
Steel (above 1400°F)	FCC
302 Stainless	FCC
Magnesium	CPH
Lead	FCC
Zinc	CPH
Titanium	CPH

Fig. 14-1

For this experiment we will only be considering the change in hardness vs. the percent of cold working of yellow brass. As previously mentioned, when the hardness increases, the strength also increases so we can advantageously use the fact that more strength in a metal can be obtained by cold working. Likewise, if the strength in a material has been obtained by cold working and we heat the metal, it will soften and lose strength.

To complete the Data Table, you will have to calculate the percent change in length after cold working. The equation is: the change in length with each blow/the length before striking. The strength can be found from figure 14-2.

Approximate Correlation Between Hardness and Tensile Strength

Rockwell[1]		Tensile strength 1,000 PSI	Rockwell[1]		Tensile strength 1,000 PSI	Rockwell[1]		Tensile strength 1,000 PSI	Rockwell[1]		Tensile strength 1,000 PSI
C, 150-kg. load	B, 100-kg. load 1/16 in. ball		C, 150-kg. load	B, 100-kg. load 1/16 in. ball		C, 150-kg. load	B, 100-kg. load 1/16 in. ball		C, 150-kg. load	B, 100-kg. load 1/16 in. ball	
67		350	44	114.4	208	21	99.5	110		83.2	76
66		345	43	113.8	201	20	98.9	107		82	74
65		340	42	113.3	194	19	98.1	104		80.5	72
64		335	41	112.7	188	18	97.5	103		79	70
63		330	40	112.1	181	17	96.9	102		77.5	68
62		325	39	111.5	176	16	96.2	100		76	66
61		320	38	110.9	170	15	95.5	99		74	64
60		315	37	110.4	165	14	94.9	97		72	62
59		310	36	109.7	160	13	94.1	95		70	60
58		305	35	109.1	155	12	93.4	93		68	58
57		300	34	108.5	150	11	92.6	91		66	56
56	121.3	295	33	107.8	147	10	91.8	90		64	54
55	120.8	288	32	107.1	142	9	91.2	89		61	52
54	120.2	286	31	106.4	139	8	90.3	88		58	50
53	119.6	283	30	105.7	136	7	89.7	87		55	48
52	119.1	273	29	105.0	132	6	89	85		51	46
51	118.5	264	28	104.3	129	5	83.3	84		47	44
50	117.9	256	27	103.7	126	4	87.5	83		44	42
49	117.4	246	26	102.9	123	3	87	82		39	40
48	116.8	237	25	102.2	120	2	86	81		35	38
47	116.2	231	24	101.5	118	1	85.5	80		30 24	36 34
46	115.6	221	23	100.8	115	0	84.5	78		20 11	32 30
45	115.0	215	22	110.2	112					0	28

Fig. 14-2 Table 1

MATERIALS

1 Piece of yellow brass 1/2 in. diameter, 1 in. long.
1 Oxyacetelene welding torch with bottles (only one is needed for the complete lab.)
2 Fire bricks for heating
1 Rockwell hardness tester, Rockwell-B scale
1 0 to 1 inch micrometer
1 Ball peen hammer, 1 lb
1 Heavy metal plate or an anvil
3 10 penny nails
1 Block of wood (2 X 4 about 10 in. long)
3 Paper clips

PROCEDURE

1. Obtain a 1 in. long piece of yellow brass.
2. Heat the brass with an oxyacetylene torch to approximately 600°F. You must be careful the metal does not melt. Place the metal on two fire bricks to heat. Caution! Do not pick up the metal with your fingers.
3. Cool the brass by quenching in water or by allowing it to cool in air.
4. Measure the length of the specimen with the 0 to 1 micrometer. Record in the Data Table.
5. Take the cooled brass to the Rockwell hardness tester.
6. Take a Rockwell-B hardness test and record the Data Table.
7. Place the brass on a heavy plate and strike the brass with a heavy hammer. One blow should be enough
8. Measure the length and record in Data Table.
9. Take a Rockwell hardness test and record in Data Table.
10. Repeat steps 7, 8, and 9 until the brass starts to break or the hardness goes over B-90.
11. Obtain three 10 penny nails. Heat two of the nails red hot.
12. Cool the nails in air. Do not quench in water.
13. Drive the unheated nail into a wood 2 X 4.
14. Drive both of the heated nails into the same 2 X 4. Note if these nails are difficult to drive.
15. Obtain a paper clip and straighten it out into one length of wire.
16. Grasp and bend through 180° at a point that has not already been bent.
17. Reverse the bending process at the same place until the clip breaks. Note if the clip wants to bend in the same place each time.

Length	% Change	Rockwell B	Tensile Strength
1″			

Fig. 14-3 Data Table

ANALYSIS GUIDE. In analyzing this experiment you should plot the Rockwell hardness number vs. the percent change in length after cold working.

PROBLEMS

1. How does the change in length affect the hardness and strength of yellow brass? What about ductility?
2. Why, in the first part of this experiment, was the brass heated and cooled?
3. If you welded on a piece of metal that had been extremely cold worked, would the weld area be harder or softer than before welding?
4. Why in step 17 of this experiment did the clip not want to straighten at the point of initial bend?
5. Why is it that zinc and magnesium have very low percents of elongation?

experiment 15 ELECTROPLATING

INTRODUCTION. Electroplating is one of the processes used to protect metals against corrosion and give better electrical conductivity to certain metals. This experiment will discuss the steps involved in electroplating copper and nickel.

DISCUSSION. In corrosion we know that if two metals are coupled in an electrolyte, electron flow is produced, the anode looses metal ions to the electrolyte, and the cathode gains electrons which neutralize the hydrogen ions. A similar process takes place in electroplating.

Electroplating is accomplished by a DC current in an electrolyte. The metal to be plated leaves the electrolyte and is deposited on one of the electrodes. The electrolyte is a solution that contains the positively-charged metal ions to be plated. The positive-charged metal ions are attracted to the cathode while the negative-charged ions travel towards the anode as shown in figure 15-1.

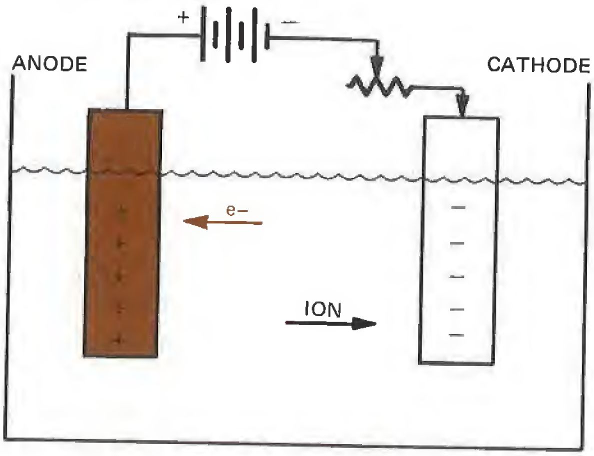


Fig. 15-1 Electron Movement

Any solution that contains ions can be used as an electrolyte. This experiment will use two electrolytes. The first is a copper sulfate electrolyte made by mixing copper sulfate in distilled water and adding sulfuric acid to the solution very slowly. (NEVER POUR WATER INTO ACID.) This will be the copper plating solution. The other solution is the nickel sulfate electrolyte. This solution is made by mixing nickel sulfate and distilled water, adding ammonium chloride and boric acid powder, and heating the water to about 150° F to dissolve the chemicals.

Electroplating requires a DC power supply. For this experiment a DC power supply with a maximum of eight amps at 12 volts is required. The power supply is to be connected to an ammeter and voltmeter as shown in figure 15-2.

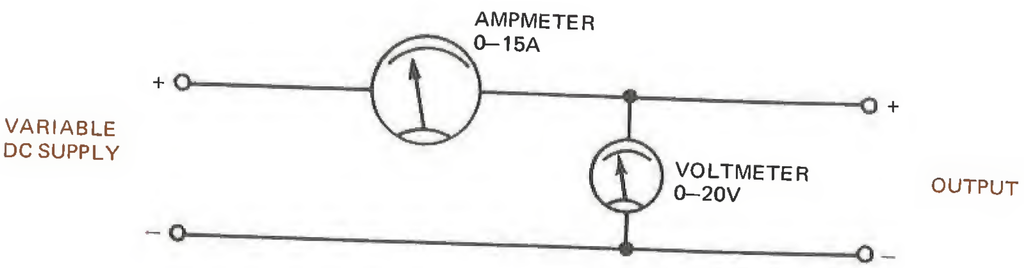


Fig. 15-2 Electroplating Circuit

The power requirements depend on the plating process used. For nickel plating, 10 to 12 amps per square foot of surface area to be plated is needed. For copper plating, 10 to 40 amps per square foot is needed. This experiment will be using small samples; therefore, small currents can be used. As the current increases, the speed of plating increases but the plating tends to peel off at high currents.

The anode in the plating process needs to be the same metal as the metal salt used in the electrolyte. When plating, the anode is consumed by liberating metal ions to the electrolyte. This replenishes the metal ions taken out by the cathode.

The cathode is where the plating process is taking place. Metal ions are coming out of the electrolyte solution and plating on the cathode. Therefore the specimen to be plated has to be connected to the negative (cathode) terminal of the meter system output.

Cleanliness is important in producing a good plated specimen. The specimen should be cleaned with emery paper to remove any oxidation or dirt. Solvent should be used to remove any oil or grease. The specimen should be washed with soap and water and then rinsed.

When plating steel a special preliminary procedure must be used to make the copper adhere. This procedure uses a weak sulfuric acid solution consisting of three quarts of water into which 10 ounces of sulfuric acid is mixed. This procedure will be explained later in this experiment.

The procedure for plating is to connect the metal to be plated to the negative terminal of the output and immerse into the electrolyte. Then connect the anode metal to the positive terminal and turn on the power supply and adjust the current.

MATERIALS

- 1 DC power supply 0-8 amps, 0-12 volts
- 1 Rheostat, 22 ohms, 50 watt (Ohmite type J)
- 1 Ampmeter 0-15 amps
- 1 Voltmeter 0-22 volts
- 9 Clip leads
- 3 Beakers 400 ml
- 1 Piece yellow brass 1/16 in. X 2 in. X 6 in.
- 1 Piece copper 1/16 in. X 2 in. X 6 in.
- 1 Piece nickel 1/16 in. X 2 in. X 6 in.
- 1 Piece steel 1/16 in. X 2 in. X 6 in.
- 1 Emery cloth
- 3 Quarts nickel sulfate solution (12 oz nickel sulfate, 1-1/2 oz ammonium chloride, 1-1/2 oz boric acid, 3 qt distilled water)
- 3 Quarts copper sulfate solution (21 oz copper sulfate, 3 oz sulfuric acid, 3 qt distilled water)
- 3 Quarts sulfuric acid solution (10 oz conc. sulfuric acid, 3 qt distilled water)

PROCEDURE

1. Connect the DC power supply, rheostat and meters as shown in figure 15-2.
2. If the nickel sulfate solution is not already prepared, mix 21 oz of copper sulfate in three quarts of distilled water, and then slowly add 3 oz of sulfuric acid.

3. Pour approximately 350 ml of the nickel sulfate solution into the 400-ml beaker. Mark this beaker **Nickel Electrolyte.**
4. Prepare the nickel sulfate solution by mixing 12 oz of nickel sulfate in three quarts of distilled water and add 1-1/2 oz of ammonium chloride, 1-1/2 oz of powdered boric acid and heat to 150°F to dissolve the chemicals. Allow to cool.
5. Repeat step 3 for the copper sulfate electrolyte and label the beaker.
6. Repeat step 2 for the sulfuric acid solution.
7. Repeat step 3 for the sulfuric acid solution and label the beaker.
8. Nickel plating brass is an easy operation so we will do this first.
9. Clean the 2 X 6 in. brass strip as stated in the discussion.
10. Connect the brass to the negative output and suspend it in the nickel plating solution.
11. Connect the 2 X 6 in. nickel strip to the positive output and suspend it in the same solution.
12. Turn on the power supply and adjust the rheostat to about 1.5 amps or to about one or two volts.
13. This plating process should take about 10 minutes. Once the plating has started do not interrupt the current flow.
14. While the nickel plating is continuing, secure a piece of steel, 2 X 6 in. Clean the steel sample to prepare for copper plating.
15. At the end of 10 minutes, turn off the power, remove the brass, rinse the specimen and dry it with a paper towel.
16. Connect the steel plate to the positive output and immerse it into the sulfuric acid solution.
17. Connect the 2 X 6 in. copper to the negative output and immerse it in the sulfuric acid solution.
18. Turn on the power supply and adjust the rheostat until gas bubbles arise from the steel and then leave on for about five minutes. This prepares the steel for nickel plating.
19. After five minutes remove the steel and copper from the acid solution and rinse in water.
20. Transfer the steel to the nickel bath and adjust the current to about 2.5 amps. Connect the nickel to the positive output and the steel to the negative output.
21. Allow the steel to nickel plate for about three minutes to receive a light nickel coating.
22. Then transfer the steel to the copper bath for 10 minutes at 1.5 amps to receive the final coating.

23. Be sure to turn off the power before removing the samples from the plating bath.

24. Try your luck at either copper or other metals or one of your other laboratory projects.

ANALYSIS GUIDE. In analyzing this experiment be sure you mention any problems that might have occurred.

PROBLEMS

1. Why is it important to add acid to water NOT water to acid?
2. Will increasing the current in plating shorten the time of plating? With what effect?
3. The metal to be plated is to be connected to which terminal of the output? Why?

EXPERIMENT 1 ____________ Name ____________________

Date: ____________ Class ________ Instructor ____________

Ring No. 1 F =

Δ	p (psi)	pA	F + pA

Ring No. 2

Δ	p (psi)	pA	F + pA

Fig. 1-11 The Data Tables

Rings in Series

Δ_2	Δ_2	p (psi)	pA	F + pA

Rings in Parallel

Δ_1	Δ_2	p (psi)	pA	F + pA

Fig. 1-11 The Data Tables (Cont'd)

EXPERIMENT 2 ______________ Name ______________________

Date: ______________________ Class __________ Instructor ______________

Force Transducer #1 **k =**

Transducer Position	Deflection Δ	Force, lb P	Hyd. Press p	Piston Area A	Load, lb

Force Transducer #2 **k =**

Transducer Position	Deflection Δ	Force, lb P	Hyd. Press p	Piston Area A	Load, lb

Fig. 2-14 The Data Tables

EXPERIMENT 3

Date: ______________________ Name ______________________

Class ____________ Instructor ______________________

Force Transducer #1 k =

Transducer Position	Deflection Δ	Force, lbs P	Hyd. Press p	Piston Area A	Load, lbs

Force Transducer #2 k =

Transducer Position	Deflection Δ	Force, lbs P	Hyd. Press P	Piston Area A	Load, lbs

Fig. 3-10 The Data Tables

EXPERIMENT 4

Date: ____________________

Name ____________________

Class ____________ Instructor ____________

Specimen	Width	Thickness	Area

Elongation δ	Strain ϵ	Hyd.Press ρ	Hyd Cyl Area A_c	Load P	Specimen A	Stress s

Fig. 4-8 The Data Table

EXPERIMENT 5

Date: ____________________

Name ____________________

Class __________ Instructor ____________________

Specimen	Width (in)	Thickness (in)	Area (in^2)
Soft Steel Initially			
Necked Down			

Elongation δ	Strain ϵ	Hyd. Press p	Hyd. Cyl. Area A_c	Load P	Specimen A	Stress s

Fig. 5-7 The Data Tables

EXPERIMENT 6

Date: ____________________

Name ____________________

Class ____________ Instructor ____________

Beam Flatwise

Hyd Press p	Hyd Cyl Area, A_c	Load P	Beam Deflections

Beam Upright

Hyd Press p	Hyd Cyl Area, A_c	Load P	Beam Deflections

Fig. 6-9 The Data Tables

EXPERIMENT 7

Name ______________________

Date: ______________________ Class ____________ Instructor ____________

Joint Type	Hyd Press p	Hyd Cyl Area, A_c	Actual Load P at Failure	Predicted Load at Failure
A				
B				

Fig. 7-8 The Data Table

EXPERIMENT 8

Date: ______________________ Name ______________________

Class ______________ Instructor ______________

Specimen	Rockwell B	Rockwell C	uts	Can you Bend*	Does Hack saw Cut**
A. Yellow Brass					
B. 2024-T6 Aluminum					
C. 1018 steel					
D. 304 Stainless					
E. Drill Rod					
F. Tool Steel					
G. Tongue of file					
H. Body of file					
I. Unknown					
J. Unknown					

Fig. 8-2 The Data Table

EXPERIMENT 9 Name ______________________

Date: ______________________ Class ____________ Instructor ______________________

Specimen	Rockwell C
1010	
1020	
1030	
1040	
1060	
1090	

Specimen	Rockwell C	Toughness*
As quenched, Not Reheated		
Reheated Straw, 450° F		
Reheated Blue, 590° F		
Reheated Gray, 720° F		

*Record number of blows

Fig. 9-4 The Data Tables

EXPERIMENT 10 ____________ Name ____________________

Date: ____________________ Class ________ Instructor ____________

Specimen	Rockwell B
Step 2 as received	
Step 7 as quenched	
Step 11 as quenched	
Step 13 air-cooled	

Table 1

time	RB	time	RB	time	RB
2		15		50	
4		20		65	
6		25		80	
8		30		95	
10		35		110	

Table 2 After Quenching – Left at Room Temperature

time	RB	time	RB	time	RB
2		15		50	
4		20		65	
6		25		80	
8		30		95	
10		35		110	

Table 3 After Quenching – Left in Hot Water

Fig. 10-2 Experimental Data

time	RB	time	RB	time	RB
2		15		50	
4		20		65	
6		25		80	
8		30		95	
10		35		110	

Table 4 Air-Cooled

Fig. 10-2 Experimental Data (Cont'd)

EXPERIMENT 11 Name ____________________

Date: ____________________ Class ____________ Instructor ____________________

Metal	Voltage
Magnesium	
Zinc	
Aluminum	
Steel	
Lead	
Tin	
Copper	
Stainless	
Platinum	

Table 1

Couple	Voltage
2 in. wide copper 1/4 in. wide steel	
1/4 in. wide copper 2 in. wide steel	

Table 2

Fig. 11-2 The Data Tables

EXPERIMENT 12 Name ______________________

Date: ______________ Class __________ Instructor ______________

	A	B	C	D	E	F	G
Plastic	Ease of Ignition	Burning Rate	Flame Size	Color of Flame	Amount of Smoke	Odor	Other
1. Acetal							
2. Acrylic							
3. Cellulose Acetate							
4. Polyethylene							
5. Polystyrene							
6. PVC							
7. Nylon							
8. Teflon							
9. Unknown #1							
10. Unknown #2							

Fig. 12-1 Experimental Data, Flame Test

Plastic	Visual Characteristics
1. Acetal	
2. Acrylic	
3. Cellulose Acetate	
4. Polyethylene	
5. Polystyrene	
6. PVC	
7. Nylon	
8. Teflon	
9. Unknown #1	
10. Unknown #2	

Fig. 12-2 Experimental Data, Visual Characteristics after Burning

EXPERIMENT 13

Date: ______________________

Name ______________________

Class ____________ Instructor ______________

Plastic	SOLVENTS				
	Methylene Chloride	Ethylene Dichloride	Acetone	Trichloro-ethylene	Cyclohex-anone
Acrylic					
Cellulose Acetate					
Nylon					
Polystyrene					
Polyvinyl Chloride					
Polyethylene					

Yes - Solvent; No - Not Solvent

Fig. 13-1 Effect of Solvents on Plastics

EXPERIMENT 14

Name ______________________

Date: ______________________ Class ____________ Instructor ______________________

Length	% Change	Rockwell B	Tensile Strength
1″			

Fig. 14-3 Data Table

EXPERIMENT 15

Name ______________________

Date: ______________________ Class ____________ Instructor ______________

486